

University of Southern Queensland

School of Engineering

**Evaluation of a C-Lock Super SmartFeed trailer for controlled
feed supplement delivery in grassfed dairy applications.**

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ABSTRACT

Globally, 30% of the world's daily methane emissions is attributable to cattle production (Black et al., 2021), posing a significant environmental challenge for the Australian cattle industry. As a developing industry solution, feed supplements for the purpose of methane mitigation are being researched for industry use. This thesis evaluates the viability of the C-Lock Inc. Super SmartFeed (SSF) system for the precision delivery of such supplements in grassfed dairy applications. Conducted in collaboration with the Tasmanian Institute of Agriculture (TIA), a cohort study following the interaction behaviour of 73, 2-year-old Friesian heifers was performed and evaluated. Interaction behaviour was monitored through RFID ear tags, MooMonitor+ collars, and built in computer systems at the SSF, all of which have been used in the evaluation of the system's efficacy for use in industry applications.

It was identified that at least 80% of the herd interacted with the SSF, with 68.89% of interactions occurring within the first four hours that feed allocations became available ($p < 0.001$). Feed delivery can therefore be manipulated to target animal rumination, which peaks between the hours of 10:00 and 19:00. SSF programmed feed delivery is 99.8% accurate, although actual delivery can vary by up to 9.12% of the target allocation. This falls within an acceptable delivery range for the majority of methane mitigating supplements. With four available feed trays it was identified that the SSF has redundancy in the event of a breakdown or malfunction, with the system experiencing an 8.21% loss in mass delivery when operating at three quarter capacity.

The findings of this study support that the SSF is a reliable system which can be used for the delivery of methane mitigating supplements in grassfed environments. As such, the implementation of these technologies on a commercial scale has the potential to greatly improve the Australian agricultural industry's impact on the environment.

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GLOSSARY OF TERMS

ANOVA	=	Analysis of Variables
ARM	=	Antibiotic Rumen Modifiers
DM	=	Dry Matter
DMF	=	Direct-Fed Microbials
DMI	=	Dry Matter Intake
EMM	=	Estimated Marginal Means
EOs	=	Essential Oils
G-G	=	Greenhouse-Geisser
GPS	=	Global Positioning System
Heifer	=	A cow who has not yet produced a calf
H-F	=	Huynh-Feldt
HSD	=	Tukey's Honesty Significance Difference
NLIS	=	National Livestock Identification System
PAF	=	Pasture Allocation Frequency
PAC	=	Powdered Activated Carbon
RFID	=	Radio Frequency Identification
RM ANOVA	=	Repeated Measures ANOVA
SSF	=	Super SmartFeed
TDRF	=	Tasmanian Dairy Research Facility
TIA	=	Tasmanian Institute of Agriculture
TMR	=	Total Mixed Ration

CHAPTER 1. INTRODUCTION

Climate change poses a global challenge for all industries to reduce their greenhouse gas emissions. In agriculture, cattle are well known for their production of methane as a byproduct of their digestion and rumination. Methane is a greenhouse gas which is 80 times more effective at heating the earth than carbon dioxide, and its production from ruminant animals accumulates to 30% of the globe's daily methane production (Black et al., 2021). With the goal of reducing the carbon footprint of the dairy and beef industries, new animal feed supplements are in the process of being developed which have the potential to mitigate the methane emissions of ruminants. Not only can these feed supplements reduce methane production, but they can also increase the efficiency of an animal's digestion and as a result their energy uptake (Black et al., 2021), increasing their overall consumption efficiency. If these supplements are developed to the stage where they are deemed safe for use in industry, the problem of their delivery arises.

1.1 THE PROBLEM

Cattle which are raised in feedlots, housed barns or are in dairy systems experience controlled feeding practices, however cattle in grassfed environments live in uncontrolled systems, where supplementary feed is typically delivered in bulk and is therefore challenging to manage at an individual level (Bowman et al., 1999). This traditional method of feeding cannot be used to deliver methane mitigating supplements as it would result in animals receiving more or less than their recommended dosage, rendering the supplement inefficient or uneconomical. In order for these mitigators to be effective, they must also be delivered to animals prior to the consumption of feed, for this requirement to be met an effective feed delivery system must be in place. A prototype feed delivery trailer has been developed by C-Lock Inc, this is an automated system with the capability to deliver

individualised feed allocations. As of yet however, it remains relatively untested in its capacity to effectively deliver supplements to grazing cattle in an industry setting, with the current scope of research focused on using the feeder as an assessment tool (Husz et al., 2020; Jacobs et al., 2023; Reuter et al., 2017). For the pursuit of methane mitigating supplements to be worthwhile to the beef and dairy industries, it must be proven that supplements can be delivered and consumed with accuracy and reliably while cattle are under grazing conditions.

1.2 PROJECT AIM AND OBJECTIVES

The aim of this study is to analyse behavioural data collected using collars and a C-Lock Inc. Super SmartFeed (SSF) trailer (C-Lock Inc., Rapid City, South Dakota, United States), *Figure 1.1*, to identify the efficacy of delivering methane mitigating supplements to grazing cattle. This was performed on the Tasmanian Institute of Agriculture (TIA) Tasmanian Dairy Research Facility (TDRF) located in Elliot, Tasmania.



Figure 1.1: C-Lock Inc Super SmartFeed trailer at the TDRF (P. Raedts, personal communication, 27 September 2024).

The TDRF is currently being used by TIA to conduct experiments with dairy cattle on feed production and animal performance, which are directly related to the needs of the Australian dairy industry.

To determine the feasibility of delivering methane mitigating supplements to dairy cattle under commercial grazing conditions using the SSF, the following research objectives have been identified:

1. Assess the interaction reliability of herd and individual animals around the SSF, with emphasis on animal supplement allocation intake.
2. Evaluate animal behaviour outside of interactions with the SSF to establish its impact on their daily activity budgets.
3. Determine the accuracy of mass delivery for the purpose of delivering methane mitigating supplements in a commercial grazing environment.
4. Determine the impact of a systems malfunction on interaction behaviour, with emphasis on feed intake, including the built in redundancy of the SSF.

In achieving these objectives, this study will provide valuable insight to the dairy industry on the feasibility of delivering methane mitigating supplements using an SSF system, to dairy cattle under commercial grazing conditions.

1.3 SUMMARY OF STUDY

The contents of this paper can be summarised into the following chapters.

Chapter 2 comprises of a literature review exploring methane mitigating substances, cattle behavioural characteristics, and previous research using an SSF system. This chapter aims to provide the foundations for the work done in this thesis.

Chapter 3 defines the conditions by which this study was performed, and establishes the statistical tools used to analyse the collected data, and defines the purposes of MATLAB scripts and functions.

Chapter 4 delivers the results and findings obtained from the experimental trial, and provides a detailed discussion on the meaning of the results and their implications for the dairy industry.

Chapter 5 draws conclusions from the work completed in this study and makes recommendations for future work.

CHAPTER 2. BACKGROUND AND LITERATURE REVIEW

2.1 THE CATTLE INDUSTRY IN AUSTRALIA

The Australian beef industry is a significant contributor to agricultural production in Australia, contributing over \$12.7 billion (Greenwood et al., 2018) and accounting for over 18% of all agricultural economic production as of September 2024 (ABARES., 2024). With the Australian herd having grown over the past 10 years, numbers have settled to 28.6 million cattle and as of 2024 (Meat & Livestock Australia, 2024) production is increasing, requiring producers to better utilise labour resources, improve feed to weight-gain efficiencies, and improve animal welfare through innovation to meet market demands.

2.2 AUSTRALIAN DAIRY INDUSTRY

The average herd size for Australian dairy farms is in excess of 500 animals as of the 2022-23 season, multiplied by the 5000 active farming operations this comes to a total herd size of approximately 2.5 million across the nation (Topp et al., 2024). The dairy industry is the third largest employer in the Australian agricultural industry (Ryder & Welsford-Brink, 2024), making it a vital component of the economy. Relative to the broader agricultural industry which exports 72% of its product as of March 2024, the dairy industry exports only 39% (Ryder & Welsford-Brink, 2024), partially due to limited shelf life of fresh milk, which is prioritised for local markets. The Australian dairy industry was responsible for the release of just under 10 metric tonnes of CO₂ equivalent emissions in 2021 (Ryder & Welsford-Brink, 2024). As a key component of Australian agriculture, the dairy industry, along with beef and livestock, will face a variety of challenges surrounding labour, husbandry and

environmental emission requirements which will need to be controlled over the coming years.

2.3 CHALLENGES FACING THE INDUSTRY

With the onset of climate change pushing the agricultural industry to increasingly reduce its environmental impact, the beef and dairy industries are expected to contribute their part. In a business where animal production systems are a contributing factor to greenhouse gas emissions, new methods must be developed to reduce the environmental impact of consumer demand for animal products. Domesticated animals account for approximately 94% of total global greenhouse gas emissions from animals (Milich, 1999) and it is therefore of utmost importance that methane emissions be mitigated from industry (Haque, 2018). Research over recent years has extended into medicinal feed supplements with the capacity to reduce or mitigate the methane production of cattle (Hegarty et al., 2021). These supplements have the potential to decrease the emissions of these animals while also giving them a boost in energy absorption capability, by transforming previously wasted energy dense methane into energy sources which can be utilised by the animal (Martin et al., 2010). While these supplements are being developed, the challenge arises of industries capacity to deliver them with accuracy and reliability to animals which live in traditionally uncontrolled grazing environments. Precision feed delivery will be required by industry to achieve this, however it is currently an uncommon technology for graziers to implement (Tzanidakis et al., 2023).

2.4 THE RISE OF PRECISION LIVESTOCK FARMING

Computer-controlled feed delivery has been a topic researched since before the 2000s, although while implemented in specific cases, it has never been broadly adopted by industry as a method of delivering feed supplements to grazing cattle. There are numerous reasons

for minimal industry uptake, including cost, maintenance, and limited accessibility in large herds (Husz et al., 2020; Marmont et al., 2024), however with the potential inflow of methane mitigating supplements into the market, new reasons for considering and developing these technologies are exposed.

Animal feed supplements have many forms, such as hay and silage fodder or grain, which is added to an animal's diet when standard forage is insufficient (Auldism et al., 2016). Feed supplements however have grown considerably more complicated, and now take a variety of forms which have a wide range of purposes, improving animal welfare and growth rates through diet and making farming more efficient (Imaz et al., 2019). As feed supplements develop and grow more complicated, the need for controlled feeding and management has also increased, especially for methane mitigating supplements when compared with traditional supplements of grain, hay, or silage (Almeida et al., 2021).

There are a wide variety of feed additives being trialled in the agricultural industry which have the potential to reduce methane emissions (Hegarty et al., 2021). A broad range of ruminant feed additives which exhibit methane mitigating behaviour include: Bovaer, Asparagopsis, Nitrate, Essential Oils, Saponins and Tannins, Biochar and Bacterial/Fungal direct feed microbials (Hegarty et al., 2021). There are currently a variety of factors which influence the viability of these additives in agricultural production systems which have been investigated in a wide range of articles (Hegarty et al., 2021). If the right delivery method were identified and budget sufficient, any of these supplements could be used safely and effectively, potentially providing a way for the beef and dairy industries to reduce their environmental impact.

C-Lock Inc. has developed cutting edge feeder technology, designed to control cattle biological parameters, allowing for researchers to monitor, analyse and control feed supplements (Husz et al., 2020). The Super SmartFeed trailer is one of their products which has been used by researchers to identify animal training behaviour (Jacobs et al., 2023) and competition between animals (Husz et al., 2020), in grassfed environments. This feed system can effectively deliver up to four different feed additives to animals and could ideally be used across industry to deliver modern feed supplements economically. Unfortunately, this product is predominantly a research tool and is not readily commercially available, additionally, other feeder products available to grazing based systems are simple and offer little to no control over individual feed supplement intake except for in custom designs (Bowman & Sowell, 1997). As a result, there is currently no feeder system available to grassfed farms which allows modern, high tolerance feed supplements to be used.

This review will outline why feed supplementation is important, and the nuances and challenges of providing methane mitigating supplements to cattle in grazing systems, with a particular focus on dairy cattle. The current precision livestock feeding technologies available will also be reviewed, as well as how the monitoring of cattle behaviour can be used to assist in determining the efficacy of feed supplement delivery systems.

2.5 SUPPLEMENTATION OF GRAZING CATTLE

Providing supplements to cattle in forage-based grazing systems presents many challenges. The main challenge, however, comes down to the lack of suitable infrastructure capable of delivering the supplement. Group feeding can be managed by ground feeding, using troughs or offering restricted supplements in the form of blocks or loose-lick tubs. Ground feeding is predominantly performed using hay or silage, whereas grains and pellets are generally delivered from trough systems, finally salts and minerals can be condensed into lick-block

forms for animals to interact with outside of normal feed consumption. Historically, individual precision feeding has been predominantly utilised in research and controlled housing environments, and their use within largescale industry is in its infancy (Marmont et al., 2024). However, recent advances have made it commercially viable with the introduction of precision feeding systems like the SmartFeed Pro (C-Lock Inc., Rapid City, South Dakota, USA), which will be reviewed further below.

2.5.1 Methane mitigating supplements

The range of methane mitigating supplements being research for industry adoption come from a variety of sources and are designed for different purposes. Each of these supplements works as a rumen modifier or inhibitor (Hegarty et al., 2021). Broadly, modifiers target processes which limit the amount of hydrogen and carbon dioxide available in the rumen, limiting methane production. Alternatively, inhibitors directly prevent the growth of methanogens in the rumen, stopping the production of methane. Research has shown that while more effective, inhibitors are not as well understood in terms of the long-term implications of their use, and therefore modifiers are currently the more trusted option to experiment with in cattle consumption (Hegarty et al., 2021). While a detailed summary of each of the supplements available is outside the scope of this review, a range of some of the most researched ruminant feed additives which exhibit potential methane mitigating behaviour will be explored in the following subsections, including potential delivery mediums and requirements. Supplements used for the purpose of methane mitigation also have the potential to be used for carbon credits in Australia, an incentive which has the capacity to offset additional expenses associated with providing the supplementary feed (Black et al., 2021).

2.5.1.1 *Bovaer*

3-Nitrooxypropanol, shortened to 3-NOP and commercially known to as Bovaer, is a feed additive which reduces enteric methane emissions by up to 39% (Dijkstra et al., 2018). The supplement works by suppressing enzymes conventionally converting rumen hydrogen and carbon into methane, after which Bovaer breaks down into compounds naturally present in the rumen (Duin et al., 2016). Bovaer is a tolerant additive which has been trialled in numerous studies (Almeida et al., 2021; Dijkstra et al., 2018; Jayanegara et al., 2017; Kim et al., 2020), with no known health implications, although high doses have been noted to correlate with reductions in dry matter intake (DMI) in beef animals but not dairy (Jayanegara et al., 2017; Kim et al., 2020). Dijkstra et al., (2018) identifies that the extremely large grazing sector is inhibited from utilising Bovaer as a feed supplement due to limitations in feed delivery technology.

2.5.1.2 *Asparagopsis*

A variety of red seaweed, *Asparagopsis Taxiformis* contains the several methane inhibiting compounds such as bromoform and dibromochloromethane (Machado et al., 2016). These compounds exhibit varying potentials at inhibiting methane production in cattle, however efficacy can approach 79% (Abbott et al., 2020; Machado et al., 2016; McCauley et al., 2020) in freeze dried form. The mode of seaweed delivery is critical to the efficacy of the supplement, where *Asparagopsis* oils can result in up to 98% reductions in methane (Roque et al., 2021). Studies have shown that dry matter (DM) inclusion should be limited to 1% DM to avoid feed refusal and reductions in feed consumption (Kinley et al., 2020), although some feed reductions have been linked to increased feed-to-growth ratios in growing beef steers (Roque et al., 2021). Bromoform is considered a human and animal carcinogen, although many studies have validated no impact on animal health or product safety after an

animal has been exposed to the compound (Kinley et al., 2020; Roque et al., 2019; Roque et al., 2021; Stefenoni et al., 2021). This, and the high tolerances required for feed delivery are barriers to industry adoption, where a precision feed delivery system would rectify one of these two issues.

2.5.1.3 *Nitrates*

Nitrates (NO_3) are highly soluble salts which reduce readily in the rumen, consuming hydrogen in doing so which would otherwise be used to create methane (Hegarty et al., 2021). This relationship can be expected to reduce methane emissions in a predictable manner, where for every 62 g (1 mol) of nitrate consumed methane production will be decrease by 16 g (1 mol) (Lee & Beauchemin, 2014). This relationship is not always seen due to methane oxidation (Liu et al., 2017), however, holds true with an efficacy of >80%. The result of this is that 1% nitrate inclusion in DM reduces methane production by 12.5% in grazing animals (Charmley et al., 2016; Feng et al., 2020). Typically, dosage is limited to 2% DM due to the presence of toxic nitrate in the form NO_2^- , which can enter the blood stream before causing poisoning and death (Villar et al., 2021). These supplements are available commercially all over the globe, while limitations for use include cost and the risk of death by poisoning due to nitrate absorption. Slow-release nitrates are being researched which are safer for animals to consume (de Raphélis-Soissan et al., 2017; Lee et al., 2017), however it is noted that most delivery methods for grazing animals revolve around lick blocks. Due to limited interaction with this kind of technology it is difficult to deliver enough nitrate to be worthwhile (Hegarty et al., 2021), as such computer-controlled delivery is a viable option to ensure correct intake quantities.

2.5.1.4 *Antibiotic Rumen Modifiers*

Antibiotic Rumen Modifiers (ARMs) have a variety of modes of action due to their many different forms, the most researched for use in methane mitigation is monensin, which has been found to impose a 5% reduction in methane production with a 4% decrease in gross energy intake (Hegarty et al., 2021). ARMs work by changing the balance of hydrogen production and use by microbiota in the rumen, reducing the hydrogen available for conversion into methane (Hook et al., 2009). Monensin is an effective tool against bloat in dairy cows (Bartley et al., 1983), and therefore provides additional gains for graziers with bloat inducing pastures such as alfalfa, clover and wheat, past that of reducing methane emissions. For use in methane mitigation, dosage may vary between 16-50 mg/kg DM, however as an antibiotic its usage is limited within the market due to market regulations.

2.5.1.5 *Essential Oil Blends*

Essential Oils (EOs) are plant-based compounds which are hydrophobic. It has been observed that best EOs for the mitigation of methane in cattle originate from thyme, oregano, cinnamon, and garlic (Cobellis et al., 2016). There are various methods by which it has been observed EOs mitigate methane, although there is some variation amongst literature, limiting a cohesive understanding of their mechanism (Hegarty et al., 2021). Support for the efficacy of these supplements is therefore weaker than for Bovaer, Asparagopsis, and Nitrates, however the most effective EO blend available to market is Agolin (Alltech, Nicholasville, Kentucky, USA) which enables an 8.8% reduction in methane emissions, delivered at a dosage of 1g/day/cow (Belanche et al., 2020). A 10% reduction in methane emissions was found by another study in dairy cows, whilst simultaneously significantly increasing milk production using Agolin (Hart et al., 2019). The use of EOs may be constrained by their volatility and instability during storage and feed processing, in addition

to their cost relative to expected gain. It has been identified that further research is required to determine the safety and reliability of delivering EOs to cattle for methane mitigating purposes (Benchaar & Greathead, 2011).

2.5.1.6 Saponins and Tannins

Saponins and Tannins are compounds known for antibacterial and antioxidant health benefits. A combination of 23 studies have shown that saponins derived from quillaia, tea and yucca have the capacity to reduce methane emissions by 7.9%, 13% and 22.3% respectively (Jayanegara et al., 2014) from doses up to 500mg/g DM. Saponins have a variety of modes of action, however generally reduce methane production by selectively inhibiting bacteria (Goel et al., 2008). Maximum methane mitigation has been identified at less than or equal to 0.5% dietary inclusion (Ridla et al., 2021). Tannins work differently to saponins, and bind strongly with proteins in the rumen (Patra & Saxena, 2011), after which the process of mitigating methane emissions varies depending on the supplement type (Verma et al., 2021). Jayanegara et al., (2014) identified in a review of studies, that supplement dosages of tannins above 40g/kg impacted feed palatability and thus supplement intake. At these doses a 5.9% reduction of methane production was observed in meta-analysis (Orzuna-Orzuna et al., 2021). No toxicity or hazard has been identified for consumers for the intake of saponins (Oleszek & Oleszek, 2020) or tannins (provided the dosage rate is adhered to).

2.5.1.7 Biochar and activated carbon

Biochar is the product of organic pyrolysis (combustion in an oxygen depleted environment), and can be created from many organic products. Biochar is an excellent filter of toxins and has therefore been used historically to absorb toxins which have been consumed by unwitting animals (Schmidt et al., 2019). Biochar is often created from waste

products, in the aim of progressing society towards a more circular economy, and there is therefore a wide range of biochar being trialled in research, produced with varying methodologies. Due to inconsistency, many researchers have found little to no methane mitigation potential for this product (Black et al., 2021), however when the product is purified into activated carbon, methane mitigation of 30-40% in dairy cows can be achieved (Al-Azzawi et al., 2021) whilst also improving milk production and quality. This result was achieved at an inclusion rate of 0.5% DM, using Powdered Activated Carbon (PAC) (Activated Carbon Technologies Pty Ltd., Victoria, Australia) with 99% particle size specifications passing the American Standard Test Series at mesh size 100 (Al-Azzawi et al., 2021).

2.5.1.8 Bacterial and Fungal Direct-Fed Microbials

Direct-Fed Microbials (DMFs) contain live microorganisms of bacteria or fungi which are fed to cattle for the general purpose of improving gut health in the rumen (Hegarty et al., 2021). Bacterial DMFs have been investigated in a variety of studies for methane mitigating traits however, those which are currently available do not exhibit this potential (Jeyanathan et al., 2019; Vyas et al., 2016). There is future capacity for methanotrophic DMFs to be researched for methane mitigation due to their capacity to directly impact hydrogen and methane in the rumen (Hegarty et al., 2021). Fungal DMFs have been researched less than their bacterial counterparts and also exhibit limited application as methane mitigating supplements (Darabighane et al., 2019), where only one paper identified a 5% reduction of methane emissions in cattle fed this supplement (Cagle et al., 2020). In this study, doses were varied in their efficacy dependant on the diet of the animal, although results were not consistent. For this reason, DMFs are not found to be an effective method of methane

mitigation, however they can provide positive influences on animal health (Hegarty et al., 2021).

A summary of the effectiveness of each methane mitigating supplement and their required dosages are listed in *Table 2.1*. It should be noted that a wide range of studies have been undertaken with varying results for each of these products. Listed here are the most reliable results found by a Global Research Alliance headed by the New Zealand Government. The purpose of which was to define the supplements currently being considered for methane mitigation within the industry, and identify the efficacy of their use.

Table 2.1: Table of methane mitigators, their efficacy and dosage (Hegarty et al., 2021).

Methane Mitigator	Methane Reduction (%)	Dosage
Bovaer, 3-Nitrooxypropanol, 3-NOP	23-39%	40-340 mg/kg DM
Freeze dried Asparagopsis meal	80-98%	0.2-0.91% DM
Antibiotic rumen modifiers	5%	16-50mg/kg DM
Nitrate	12.5%	1-2% DMI
Essential oil blends	<8.8%	1g/day/cow
Saponins and Tannins	8.6%; 5.9%	<0.5% DMI; <40g/kg DM
Biochar and activated carbon	0-40%	0.5-1% DMI
Bacterial and fungal DMFs	~	~

These products show a wide range of dose requirements and are expected to be produced by manufacturers in a manner which can be incorporated into feed delivery systems (Hegarty et al., 2021). With a variety of forms, including oils, powders, pellets and dry feed, general practice is expected that a computer-controlled method of feed delivery would deliver a pre-mixed concentrate ration, however there is potential that a future feed delivery system could incorporate supplement mixing at the feeder.

2.6 PRECISION LIVESTOCK FEEDING TECHNOLOGIES

Individually supplementing animals is both expensive and time-consuming, making it impractical for large-scale commercial operations (Sinnott et al., 2022). However, precision technology makes it possible to supplement animals individually without the additional labor and time required for daily manual group feeding. Moreover, many precision feeding systems can measure individual animal intake, which is essential for evaluating performance factors like feed efficiency.

The swine industry, particularly in grow-finishing operations, has widely adopted precision feeding, with studies like those by Pomar and Remus (2019) showing that it has decreased nitrogen and phosphorus excretion by 40% and reduced greenhouse gas emissions by 6%. This has been achieved through the use of total mixed ration (TMR), and no supplements for the express purpose of methane mitigation were utilised, illustrating the potential even of tailoring individual diets to animals for reducing the impact of animal agriculture on the environment (Pomar & Remus, 2019).

Identifying how smart feed delivery systems can be used in industry requires a thorough understanding of all systems currently being implemented in agriculture. Feed delivery systems in agriculture are diverse in design, and in their simplest form a farmer can simply place feed on the ground for animals to consume at their leisure. Alternately, for the purpose of research, academics can use computer-controlled delivery systems to precisely monitor animal feed consumption and emissions (Hammond et al., 2016). In between these options are a range of standing feeders, bowl feeders and dispensers which offer varying degrees of control. Devices used for the precise control of feed supplement delivery have been investigated later in this section.

2.6.1 Animal behaviour trait definitions

There are several animal behavioural traits which are touched on frequently when analysing cattle behaviour, in this section these shall briefly be given definition, as it is critically important to have an understanding of these terms when looking to analyse feeding behaviour. Traditional feeding behavioural traits are listed below, these are daily recordings of feed intake on an individual animal basis relating to feeding events, and daily total results (Kelly et al., 2020):

- Feed event intake (kg)
- Feed event duration (min)
- Time between feed events (min)
- Number of feed events per day
- Total feeding time (min); the summation of total daily feeding time per animal
- Total feed intake (kg); the summation of total daily feed event intake per animal
- Feeding rate (kg/min); total feed intake / total feeding time

In addition to these basic behavioural traits, concepts such as dry matter (DM), dry matter intake (DMI), and dominance are important to understand, where the former two relate to values of feed consumption. Dominance is a descriptor for the social hierarchy of cattle, where animals with greater dominance have propriety of resources (Kelly et al., 2020). By observing animals which ‘dominate’ a feeding station these animals can be identified, and their behaviour observed. More importantly, their influence on other animals around a feed system can be observed, this is an important aspect of behavioural analysis and could aid in the identification of control systems which limit such behaviour.

Several companies have developed electronic feeders for cattle that use radio frequency identification (RFID) technology to monitor individual feed intake and behaviour. These systems, such as the GrowSafe feeder (Canada), Hokofarm Group's Insentec feeder (Netherlands), and C-Lock's SmartFeed feeders (USA), are also commonly used in research settings and feedlots. Each of these systems will be briefly reviewed below.

2.6.2 Insentec feeder system

The Insentec device (Insentec, Marknesse, Netherlands) provides researchers with measures of feed and water intake through RFID collars or ear tags (Huzzey et al., 2007; Tolkamp et al., 2000). This system is used for animals which are loose-housed, individually identifying animals and delivering them with a feed amount which is pre-allocated (Hanson, 2023). As such, the system has the capacity to control supplement intake and feeding time through restrictive means (Chapinal et al., 2007). The design of this system has been orchestrated to be incorporated into yard and barn infrastructure and is therefore unsuitable for use in grassfed applications, although its delivery method is similar to that used by other computer-controlled systems.

2.6.3 The GreenFeed trailer

C-Lock Inc. (South Dakota, United States) has developed a device used for the monitoring and measurement of feed delivery and emissions outputs of grazing animals. Similar to other computer-controlled feeding systems, the GreenFeed uses RFID tag identification to deliver supplements to individual animals. In addition to this, the GreenFeed system has the capacity to monitor environmental factors such as temperature and ambient humidity whilst also measuring methane and carbon dioxide emissions from animals interacting with the system during exhalation (Hammond et al., 2016). This feed delivery system is incorporated into a

trailer design which allows it to be moved to various locations, making it suitable for use in monitoring grazing animals in research. Due to the complexity of the design however, one feed bin is available for use by the interacting animals, limiting testing applications to small herd sizes which are not representative of most industry settings.

2.6.4 The SmartFeed trailers

Three SmartFeed systems have been developed by C-Lock Inc. for the purpose of comparing and contrasting feed supplements being researched for use in agriculture. The three systems are variations of one overarching design, and are called the SmartFeed, Super SmartFeed and SmartFeed Pro (Hanson, 2023). As with other computer-controlled feeding systems each of these trailers utilises RFID sensors to identify individual animals within a herd, to deliver pre-programmed quantities of feed (Reuter et al., 2017). It should be noted that the accuracy of RFID animal identification can be influenced by aberrant behaviours such as rubbing or pushing against the trailer, which can influence the analysis of interaction behaviour (Simanungkalit et al., 2021). These trailers are equipped with four feed bins with a total capacity of 2.5 tonnes, each with the capability to deliver separate feed types. All variations of this system are equipped with a solar panel, batteries, and the required electronics to ensure the reliable and sustained delivery of feed supplements, with antenna which enable the remote collection of data.

Key differences between the design variations are described as follows. The SmartFeeder does not have a mechanism restricting the intake consumption of up to 0.23m³ of feed stored in the volume of each feed tray (Hanson, 2023). The SmartFeed Pro trailer system contains an additional control to manage animal access to feed at the feeder trays. This variation has a built-in gate system which closes off access to feed if an animal which is scanned through RFID has already consumed its daily intake. The closing of this gate is monitored and

controlled by an algorithm which times the rate of feed consumption with expected daily allotment. The Super SmartFeed system (SSF) is a design which resides between the SmartFeed and SmartFeed Pro. The SSF utilises a drag chain delivery system resulting in 'cup drops' which manage the delivery of feed to individual animals. This method of feed delivery inevitably opens the possibility for feed to be left behind, potentially resulting in some variation in the quantity of feed dispensed (Hanson, 2023). The system is equipped with five scales to monitor feed delivery, four at each feed tray, with a primary scale measuring total capacity. Feed is delivered in 10 second increments if an animal is eligible to feed, in time with the rate of consumption, ensuring leftover feed is minimised.

Husz et al., (2020) identified a delivery variation of 0.07 and 0.15 kg standard deviations from the desired feed quantity when performing feed delivery validations using the SSF. The impact of this variance is dependent on the tolerance of the specific feed supplement being used. It is suggested by Husz et al., (2020) that future research should consider this limitation of the delivery system if high precision is required, with this suggestion opening the opportunity for methods of greater accuracy to be investigated.

Jacobs et al., (2023) used this method to identify training behaviours of cattle interacting with a SmartFeeder system, identifying daily supplement intakes of 90% within two days in cases where cattle had previously been exposed to supplements. In most other cases it was found that supplement uptake was considerably slower, especially where animals had not been exposed to feed supplements before.

Long-term studies of feeding behaviour around the feeder have not been found, with the exclusion of Husz et al, (2020), and it is suggested by Jacobs et al., (2023) these are

necessary for greater understanding of animal behaviour around a computer-controlled feed system. Likewise, to-date minimal research has been conducted in dairy grazing systems.

2.7 FURTHER CHALLENGES IN GRAZING SYSTEMS

Grazing operations are systems which have limited control over all forms of animal husbandry when compared with housed or barn systems. Over the next subsections, issues around herd grazing management, the application of controlling feed intake and animal behavioural monitoring are explored. Dairy farms are often intensive operations when compared to other grazing operations, with areas of irrigated land granting the capacity for greater yield relative to farm size. Due to the close proximity of intensive farming systems, unique management challenges arise when compared with extensive farming systems.

2.7.1 Herd grazing management

Rotational grazing is a practice which increases the production of pastures, however individual farming operations manage pastures differently depending on herd size, block size and rotation duration, influencing grazing availability and reliability for cattle. Animal feeding behaviour is a deeply complex process, however Pollock et al., (2022) identified that cattle follow diurnal grazing and ruminating patterns irrespective of parity or the reliability of grazing availability. This was found by trialling the effect of pasture allocation frequency (PAF), at 12-, 24- and 36-hour intervals with the result being 90% of grazing occurred during daytime hours in all cases with peaks at dawn and dusk (Pollock et al., 2022). Peak grazing occurred with fresh pasture allocation for the 12- and 24-hour experiments, however the animals did not exhibit the capacity to anticipate fresh pasture in the 36-hour allocation, resulting in a more even feeding distribution (Pollock et al., 2022). It was further identified that with increased PAF younger, more dominant cows exhibited

greater grazing activity, suggesting animal dominance is highlighted with more competitive feeding arrangements. It can be anticipated that cattle will interact most with a feeder system at dawn and dusk, increasing feeding competition due to increased use (Pollock et al., 2022). Additionally for cattle on a feed rotation of 36-hours or more, the effects of peak grazing should reduce, inducing more reliable feeder interaction.

2.7.2 Determining feed intake

Ensuring cattle consume prescribed feed dictates the effectiveness of any feed supplement, where animal behaviour and its causes has been comprehensively researched in previous studies. Factors influencing feed consumption include supplement type, feeding method, animal dominance and social interactions, and forage availability (Bowman & Sowell, 1997). Traditionally, ensuring individual supplement consumption in grazing environments has been challenging as alternative feed is freely available to the animals. Additionally, cattle behaviour favours herd movement, where they will visit points of interest as a group. If stocking rates are too large for the facilities available, not all animals will interact with them in the desired manner, this is identified by Husz et al., (2020), where in their trials using a C-Lock Inc. Super SmartFeed, at least 20 animals per feeder could be stocked with minimal impact on supplement intake. *Figure 2.1* displays the influence of stocking rate on number of visitations to the Super SmartFeeder with beef animals. Dairy heifers have very different temperaments to beef steers and therefore it is expected visitation numbers will be higher than those seen with beef animals due to their more domesticated nature, however as of yet this has not been investigated. A major cause of limited visitation numbers is likely attributed to only four bales being available to the animals at any one time, encouraging competition between animals. A feeder capable of feeding more animals simultaneously while maintaining or improving feed accuracy would be beneficial to larger herd sizes, such

as those commonly seen in industry. Feeder trials by Husz et al., (2020) were performed in conjunction with GPS collar location, however behavioural analysis was not performed with regards to rumination, resting and feeding patterns which, combined with interaction data would dictate the viability of delivering supplements in conjunction with pasture. This is a gap within research for the assessment of the viability of feed supplement delivery for the purpose of methane mitigation.

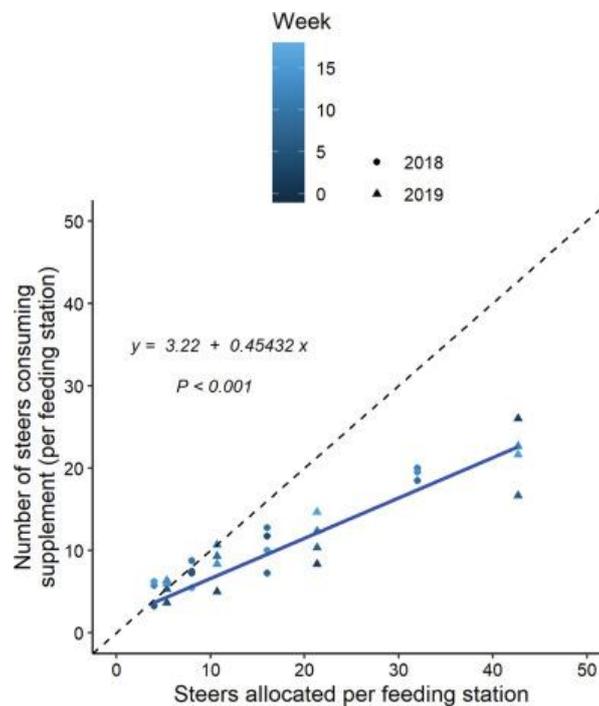


Figure 2.1: Stocking rate comparison with feeder interaction (Husz et al., 2020).

2.8 MONITORING CATTLE BEHAVIOUR

Animal behavioural analysis is required to assess the viability of systems interacted with by cattle, and is commonly used in the research of new technologies in agriculture. To determine how controlled feed delivery systems can be integrated into grassfed systems these must be investigated and analysed. There are currently a number of devices available

to do this. A review of all is beyond the scope of this research however, some of the main devices available for dairy cattle will be highlighted below.

2.8.1 Animal monitoring methods and devices

There are several methods and devices available in the agricultural industry for the monitoring of cattle, which if utilised in conjunction with an SSF would provide invaluable insight into how animals interact. Due to the intensity of the industry, the dairy sector is at the forefront of testing and trialling these new technologies. There is a plethora of devices available to farmers, however their complete review is not within the scope of this paper. A brief overview of the popular and new technologies is explored in the following subsections.

2.8.1.1 Ear monitoring

Australia has seen great success in tracking animal genetics with NLIS tags, which also enable the use of computer-controlled systems through RFID identification. Extrapolating from this success, companies and researchers have investigated tracking animals further through ear-based tags. Technologies such as the Active GPS Tag (mOOvement, South Brisbane, Australia) and Bluebell GPS SmartTag (Smart Paddock, Moorabbin, Victoria, Australia). GPS ear tags can be used to track and trace cattle/assets over long distances. Most ear tags are equipped with accelerometer and temperature sensors which enable the monitoring of rumination, resting, feeding patterns and by extension, animal health (Lee & Seo, 2021). These ear based tags provide a promising option for animal health monitoring, however other options such as head monitoring are currently more readily available in the market and are for this reason more widely useful to industry (Lee & Seo, 2021).

2.8.1.2 Head monitoring

Head monitoring devices, also known as halters may often be equipped with cameras, GPS devices, accelerometers, compasses and gyroscopes for use in assessing animal behavioural patterns (Rahman et al., 2018). Rahman et al., (2018) has identified in their study that head mounted devices generally have greater accuracy at recording head position than either ear or neck-based systems in research, although F-Score is generally high for all systems. Head monitoring systems are not common in the Australian industry, however, include systems like the RumiWatch (Itin+Hoch GmbH, Liestal, Switzerland) which is primarily used for research. This system has been validated for its capacity to monitor rumination, grazing, standing and lying patterns with high precision (Pereira et al., 2021). The RumiWatch nose band has been used to validate MooMonitor+ collars, demonstrating an accuracy of 0.98 and 0.97 for rumination and grazing respectively (Werner et al., 2019). Neck collars have the advantage over head collars of being able to monitor animal temperature more easily (Alipio & Villena, 2023) and as such can provide a broader spectrum of information to the farmer, this is one reason why they are currently the more popular option on the Australian market.

2.8.1.3 Neck monitoring

There are a wide range of animal collars, affixed at the neck, available to industry for monitoring animal behaviour, predicting reproduction and aiding farmers in managing animal health and wellbeing, with some technologies also utilising virtual fencing (Dooley et al., 2024). Some of the market options which are popular on the current Australian market include MooMonitor+ (Dairymaster, Tralee, County Kerry, Ireland), Halter[®] (Halter, New Zealand), CowScout (GEA, Düsseldorf, Germany) and SenseHub[®] (Allflex Australia Pty Ltd, Murarrie, Australia) among others. Each of these collars have been utilised in industry and have been developed with varying purposes. Halter[®] is one of the leading collar producers in the market, however farm uptake is restricted by the price of the product. These

collars are sold as a comprehensive farm management system, whereas others on the market are sold as a supplementary tool for farmers to incorporate into their current systems. Overall, collars have been a successful addition to a grazier's toolbox, aiding in health and reproductive monitoring, MooMonitor+ collars have also been expanded to monitor general animal behavioural patterns, these collars and their general workings are expanded upon further below.

2.8.1.4 MooMonitor+ collars

MooMonitor+ Collars (Dairymaster, Tralee, County Kerry, Ireland) have been used to collect accelerometer-based activity from cattle at the TIA TRDF and their data will be investigated in this thesis. These collars are secured to the animal around the neck and transmit data wirelessly to either an on-farm computer or mobile device (Moore et al., 2021). Previous studies have identified MooMonitor+ collars as effective, industry available devices for identifying animal movement, grazing, and resting patterns, as well as for oestrous activity (Moore et al., 2021; Obermeyer & Kayser, 2023).

Commercially available collars have been identified as limited in application when identifying short duration activity such as drinking or walking short distances (Benaissa et al., 2023), however this can be rectified by RFID (radio frequency identification) recognition located at points of interest. Radio frequency identification can easily be achieved using Australia's mandatory NLIS (National Livestock Identification System) ear tags already linked with each animal.

From accelerometer data recorded by the MooMonitor+ collars, ruminating, resting, and grazing is recorded. Rumination is the process cows undergo to chew and re-chew their feed and is commonly referred to as 'chewing the cud'. This process essential for the animals as

it allows them to metabolise grass more completely, vital for their multi stomach digestive system to maximise feed value. Resting or idle time is that which is taken up by sleep or where cows neither ruminate or graze, an animal cannot do either of these processes while idle (Gregorini et al., 2015). Grazing time is that which is spent consuming food sources, this can be grass or feed delivered through a feeder trough system, and the MooMonitor+ collars have shown very high accuracy in measuring this behaviour in previous research (Werner et al., 2019). These three factors are vital components of a cow's daily routine (referred to as their 'activity budget'), and their interpretation is vital to maximising the effectiveness of a feed delivery system. This is highlighted in grazing environments where feed options are available to animals.

2.8.1.5 Identification of rumination, resting and feeding behaviour

Important for drawing comparisons between feeder interactions, consumption of other feed sources and digestion of food, rumination, feeding and resting patterns of cattle are the subject of extensive research. Rumination, known as 'chewing cud' colloquially is the process where ruminants regurgitate previously consumed feed from the rumen to be re-masticated and re-swallowed (Beauchemin, 2018). Rumination is part of the digestive cycle which grants cattle and other ruminants the ability to draw nutrients and energy from foods with low energy densities. Dairy cattle can ruminate up to 10-12 hours per day, however this is dependent on the type, quality, and fibre content of the feed they consume (De Boever et al., 1990; Welch, 1982).

Measuring the rumination behaviour of cattle can be performed alongside measuring feeding and resting behaviours, although high overlap between activities can be recorded when using collar data (González et al., 2015). González, (2015) suggests such data is best analysed

using a frequency/log methodology, which was determined when analysing axial accelerometer data obtained from raw collared data as seen in *Figure 2.2*.

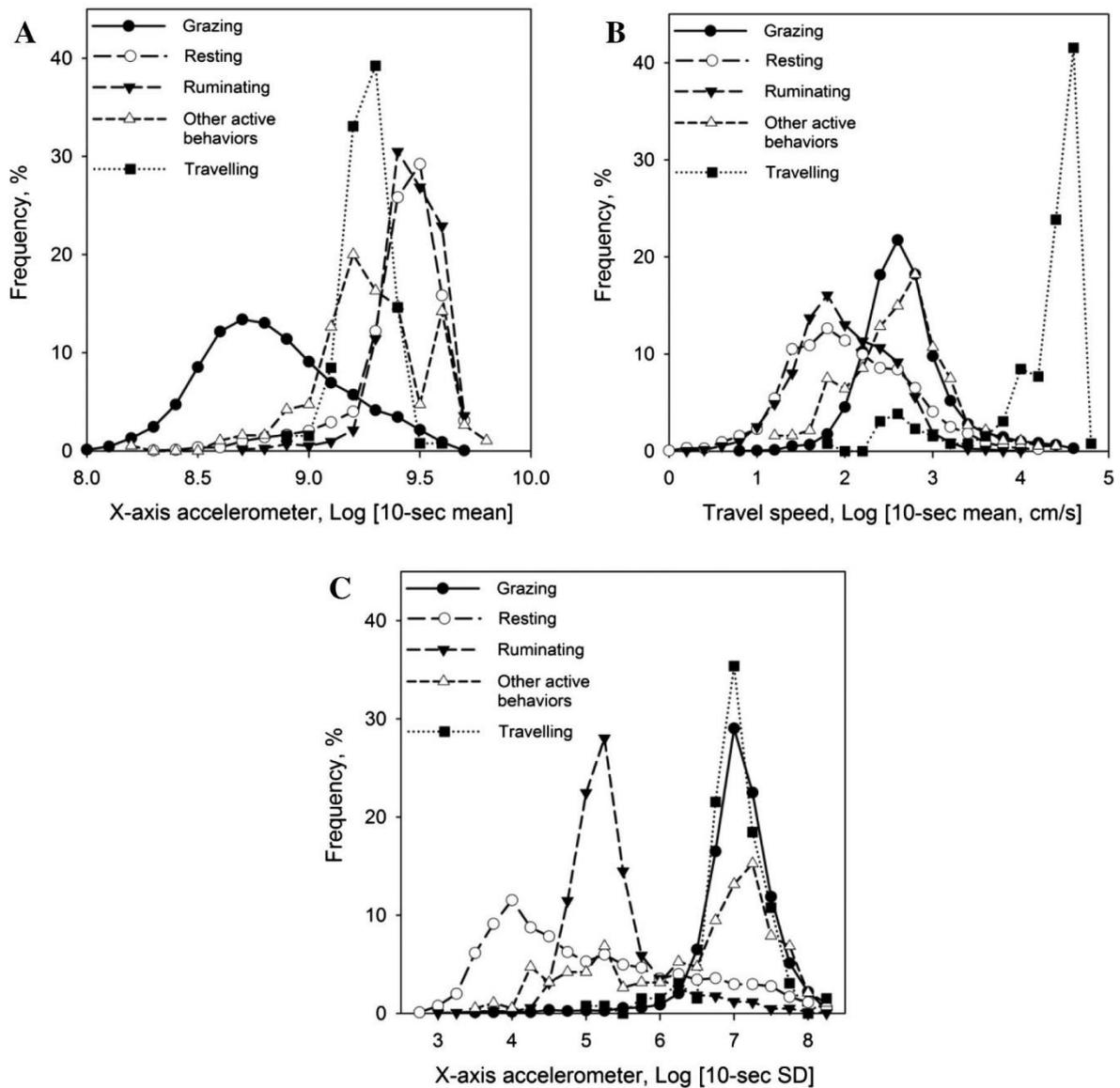


Figure 2.2: Frequency distribution of accelerometer data (González et al., 2015).

In their research of grazing patterns in dairy cows, Gregorini et al., (2015) determined feeding behaviour variation based off the 22 variables, including but not limited to grazing time, ruminating time, idling time, total steps, and laying time. These variables have been

simplified in MooMonitor+ collar data collection, and in alignment with animal interactions with the Super SmartFeeder, can be used to analyse the viability of delivering methane mitigating supplements to grazing cattle. This method would only be effective if the accelerometer collars and smart feeder time settings were synchronised with individual animal tracking, however this would need to be validated.

The considerable overlap seen in this analysis corroborates with the behaviour of grazing cattle. Such animals often move between each of these activities as an active response to the environment around them, responding to rapid and gradual changes in environment equally. As a result of this, data extracted from animal behavioural collars can often be convoluted, however conclusions can be drawn pertaining to animal behavioural tendencies from patterns in behaviour.

2.9 SUMMARY

In this literature review the background of the Australian cattle industry has been established, with relevant focus on the Australian dairy industry and their increasing environmental responsibilities in light of climate change. One of the key challenges therefore facing the dairy industry in the coming years will be the delivery of smart feed supplements for the purpose of methane mitigation. Such supplements have tolerances which will need to be delivered to individual animals in a manner which maintains animal health and welfare. Due to the wide variety of supplements being researched, their requirements and modes of actions have been studied to better understand the dose requirements they may need when being delivered to cattle. The C-Lock Inc., Super Smartfeed trailer, is one of the devices currently being researched for the delivery of feed supplements to grazing animals, and by extension those for methane mitigation. To-date however, there is currently no validation of its efficacy in combination with animal

behaviour such as that which can be recorded with animal monitoring devices. Previous literature has been reviewed for animal monitoring devices which can be used in industry, including their capabilities and functions, and it has been validated that MooMonitor+ collars are an accurate tool for the collection of cattle behavioural data. From the research investigated, the question remains as to whether the delivery of methane mitigating supplements would be a viable method for farmers to reduce their greenhouse gas emissions. From the findings of this literature review the following research questions have been identified which must be addressed if methane mitigating supplements are to be a viable option for grazing operations.

- Do dairy animals interact reliably with a computer-controlled system when alternative feed is available?
- Do the animals interact with feed supplements prior to their consumption of other feed sources?
- Can animal grazing behaviour be controlled using computer-controlled feed delivery of supplementary feed?
- Are computer-controlled feeding systems a viable method for delivery methane mitigating supplements?

Accordingly, if these research questions were to be answered, the viability of delivering methane mitigating supplements to grazing animals would be answered, providing guidance to the potential directions of future research and the application of industry development.

CHAPTER 3. METHODOLOGY

3.1 EXPERIMENTAL SITE

This experiment was conducted in collaboration with the Tasmanian Institute of Agriculture (TIA) at the Tasmanian Dairy Research Facility (TRDF) located on the north-east coast of Tasmania, along Nunns Road (Latitude: -41.082242, Longitude: 145.772264, ~150m AHD altitude), Elliot, 7325. This operation has the goal of improving productivity, profitability and sustainability by targeting industry issues aligned with feed production, animal performance, grazing management and irrigation. The experiment was conducted between the months of November 2023 and May 2024. The closest active Bureau of Meteorology weather station is 091107 Wynyard Airport Tas, located 11.1 kilometres away from the experiment site (Australian Bureau of Meteorology [BOM], 2024). Annual climate conditions from this weather station have been illustrated in *Figure 3.1* with climate conditions assumed to be similar to that experienced at the experimental site.

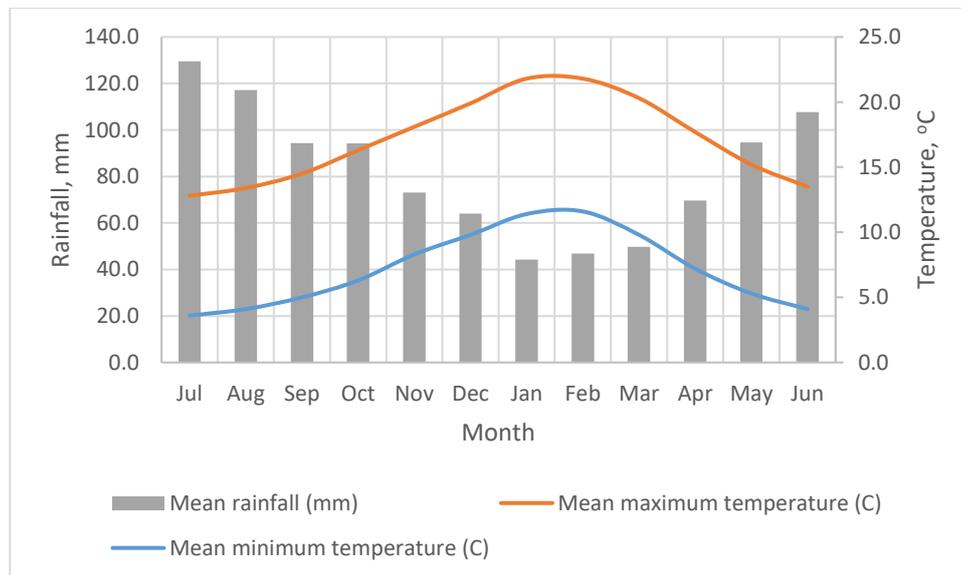


Figure 3.1: Climate conditions at weather station 091107 (Australian Bureau of Meteorology [BOM], 2024).

3.1.1 Animal ethics

All animal experimental procedures were reviewed and approved by TIA, and an animal ethics exemption was approved by the University of Southern Queensland Animal Ethics Committee, meeting the requirements of the *Australian code for the care and use of animals for scientific purposes (2013)* (National Health and Medical Research Council, 2013). The approved animal ethics exemption, number ETH2024-0093, is attached in Appendix B, with associated Research Data Management Plan in Appendix C and RMP in Appendix D.

The data used in this project belongs to C-Lock. Inc and was collected by the Tasmanian Institute of Agriculture. This data is being used for its intended purposes as requested by C-Lock Inc. by assessing the effectiveness of the feeder in farm trials.

3.2 ANIMALS AND HUSBANDRY

The experimental trial involved a herd of Friesian dairy heifers ($n = 73$), born between the months of August and October 2021. At the beginning of the trial, these animals were just over 2-years-old and weighed approximately 350-400 kg. During the trial, the supplement the animals received was a standard ration of neutral pelletised feed. During the study period the animals had *ad libitum* access to ryegrass and white clover pastures, with some areas of the grazing rotation being irrigated. As part of the grazing rotation, the herd was moved to a fresh block of pasture when grazing availability was deemed too low by the farm operators, with the grazing rotation managed in the same manner as for animals not under trial. Each animal was outfitted with MooMonitor+ (Dairymaster, Tralee, County Kerry, Ireland) collars and equipped with an NLIS tag. Potential DMI was calculated at 3.5% of the live bodyweight of these cattle, or 12.25-14 kg (Morton et al., 2007).

3.3 TRIAL DESIGN

3.3.1 Super SmartFeed trailer

The four-binned SSF used in this trial was a solar powered precision computer-controlled feed trailer designed to deliver individual allocations of feed at each of its stalls. Individual animal identification is achieved through RFID scanners equipped on the trailers which register with unique animal NLIS tags. The SSF system utilises a cloud interface to store and transmit data, where it has two days of on-board data storage available in the event of a technical malfunction. Accuracy of the SSF is partially dictated by its setup, and each of the feed trays was calibrated as per the manufacturer recommendations. In the initial days of the trial, delivery intervals from the feeder were limited to less than 0.1 kg, however as the trial progressed this was increased to ensure maximum feed allocation was achieved within six interactions. Paddock conditions vary at the experimental site and SSF location changes with paddock layout. The trial occurred over multiple seasons, where grazing availability was high during the summer months of December through February and reduced moving into the winter months. Collar data collection began one month prior to the introduction of the SSF, which accumulated to a total of 186 days of collar data and 156 days of SSF data collection.

3.3.2 Super SmartFeed trailer location

While in trial at the TDRF, the herd of rising-2-year-old heifers were managed in a rotational grazing strategy, the movements of the SSF is illustrated with time in *Figure 3.2*. The feeder location was generally positioned between paddock entrances and water troughs to encourage initial interaction.

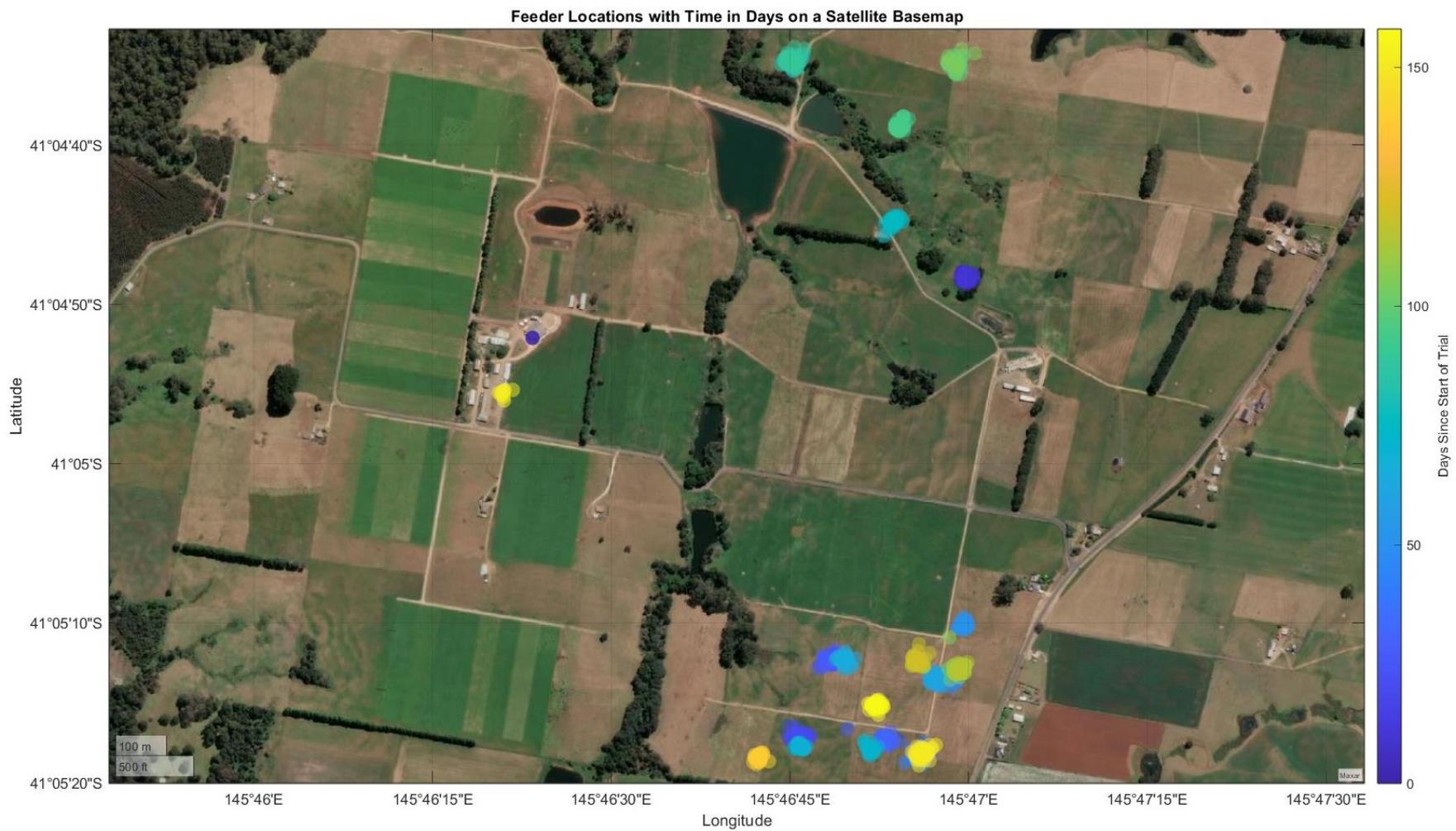


Figure 3.2: SSF locations at the TDRF from 1 December 2023 until 7 May 2024.

3.4 DATA PROCESSING, INTERPRETATION AND VISUALISATION

3.4.1 Hierarchy of evidence

The trial design can be categorised as an observational study with the methodology of a cohort study. The description of such a study as defined by Petrie & Watson (2006) is outlined as follows.

“Groups (cohorts) of animals are selected on the basis of their exposure to a particular factor and followed prospectively to see if they incur a specific outcome”.

In the context of this study, the group of animals is the herd of rising-2-year-old dairy heifers, the factor which they are exposed to is the C-Lock Super SmartFeed trailer, and the outcome they are being followed for is their reliability to interact with the system.

In the hierarchy of evidence, such a study is neither the strongest nor weakest model for determining reliable results, and falls third strongest on a list of eight methodologies for assessing statistics in animal science (Petrie & Watson, 2006).

3.4.2 Data from experimental trial

Five forms of data were collected, all in .csv format which were shared for the purpose of this project. The data types collected were SSF location data, MooMonitor+ raw data, SSF commands, SSF intake mass and SSF RFIDs. The data files and their contents have been summarised in *Table 3.1* below.

Table 3.1: Summary of TIA SSF raw data.

File type	Number of files	Rows of data (all files)	Columns of data	Variables
SSF location	1	1130	3	Date
				Time
				Latitude
				Longitude
MooMonitor+ Data	3	24597	100	Cow Id
				Date
				Behaviour
				Daily Totals
SSF Commands	5	212527	2	Command Time
				Command
Calc Intake Mass	1, (later split into 2)	93242	16	Feeder Tray
				Animal Name
				Animal Tag
				Date
				Intake Kg
				Feeder
				Start Time
				End Time
				Duration
				Start Mass
				End Mass
				Mass Difference
				Feed Type
RFIDs	5	515747	4	Scan Time
				Cow Tag
				'In' or 'Out'
				Tray

These files contained significant quantities of unfiltered data which required MATLAB to process and manipulate. The different file types also have varying levels of usefulness during analysis, where key data is contained within MooMonitor+, Intake Mass and RFID data files.

3.4.3 Initial review of data

An initial analysis of data was performed to check the quality of data collected and summarise what data was available. This check highlighted any gaps in data which were expected to have occurred due to the long-term duration of data recordings. The check was performed by plotting the available data over time. Comparisons between various data sheets were then able to be drawn. Data such as time, feed intake and animal identification were recorded both through the SSF and MooMonitor+ collars which could then be compared and contrasted. Data identified in the initial review found to be unreliable was categorised as usable with limitations, or removed entirely.

3.4.4 Validation

To assess the quality of the data being used in this analysis the proportion of missing data from each file was investigated. This was performed in MATLAB by the import of all data files through the script Data Validation. From this script it was identified that almost all data was imported correctly, with the exception of Animal Name from the Intake Mass .csv. In this case, 8.6% of animal naming data was missing, which is attributed to tests and calibrations performed during the experiment as well as auto-detections of new RFID tags. All data provided by TIA was deemed otherwise valid for the experiment performed.

3.4.5 MooMonitor+ data recording

To supplement the data collected through the SSF, MooMonitor+ collars were used to track general animal behaviour as can be seen in *Figure 3.3*. These collars are industry available and are used to track individual animal rumination data including rumination, resting and feeding. Combined, these three parameters generate a general view of an animal's grazing and behavioural patterns. *Table 3.2* shows the first hour of data for cow 2201 on 1 November

2023 where she spent the majority of her time feeding, with data being collected in 15-minute intervals and the sum of all behaviours at each interval amounting to 15.

Table 3.2: Example MooMonitor+ raw data output, exclusive of all data recorded after the first hour.

Cow Id	Date	Behaviour	Total	0:00	0:15	0:30	0:45	1:00
2201	1/11/2023	Rumination	8.73	8.73	0.00	0.00	0.00	0.00
2201	1/11/2023	Resting	2.66	1.71	0.95	0.00	0.00	0.00
2201	1/11/2023	Feeding	56.76	3.99	8.73	14.42	14.62	15.00

Data for each of the animals was collected daily and compiled across three Excel .csv files.



Figure 3.3: Cattle interacting with the C-Lock Inc. Super SmartFeed trailer at TDRF. Animals are simultaneously being monitored using MooMonitor+ collars (P. Raedts, personal communication, 27 September 2024).

3.4.6 Super SmartFeed data recording

The C-Lock Super SmartFeed trailer is capable of recording animal interactions through RFID recognition with NLIS ear tags on each of the animals, *Figure 3.3*. The system is also outfitted with five separate scales, one large scale for weighing the main hopper and four small scales for weighing the feed delivered to each of the feed bins. RFID scanners are also fitted at each of the four feeding stations, recording interaction data which is compiled in conjunction with that recorded from the scales. An example of RFID data recording is provided in *Table 3.3*, where cow number 9359 (given by the last four digits of her CowTag) is seen interacting with the system over an eight-minute period. She is recorded moving between Trays 2 and 3, indicating a desire to find more feed than may be available at one time.

Scales on the SSF were calibrated every time the feed trailer was moved and were checked daily. Daily checks were performed via phone app, while a full calibration involved weighing a pre-identified mass and resetting the system if the measured reading differed from the expected mass.

Table 3.3: SSF RFID recording.

ScanTime	CowTag	InOrOut	Tray(IfApplicable)
5/12/2023 7:26	000000000964001043689359	In	3
5/12/2023 7:27	000000000964001043689359	Out	3
5/12/2023 7:32	000000000964001043689359	In	2
5/12/2023 7:32	000000000964001043689359	Out	2
5/12/2023 7:32	000000000964001043689359	In	2
5/12/2023 7:33	000000000964001043689359	Out	2
5/12/2023 7:33	000000000964001043689359	In	2
5/12/2023 7:34	000000000964001043689359	Out	2
5/12/2023 7:34	000000000964001043689359	In	2
5/12/2023 7:34	000000000964001043689359	Out	2

Responding to an animal interaction, the SSF delivers feed as per *Table 3.4*, which is a record of feed duration and mass according to animal identification and time. This data links

with that shown in *Table 3.3*. Variations in consumption of feed for individual animals and the overall herd can be identified. Using this, conclusions can be drawn regarding the reliability and viability of the SSF, and by extension, how well feed can be delivered to cattle in grassfed systems.

Table 3.4: Example SSF feed intake mass recording.

AnimalTag	Feeder	StartTime	EndTime	DurationSec	StartMassKg	EndMassKg	MassDiffKg	Tray	FeedType
'00000000964001043689359	900147	7:26:56 AM	5/12/2023 7:27	10	0.073	0	0.073	3	1
'00000000964001043689359	900147	7:32:42 AM	5/12/2023 7:32	10	0.062	0	0.062	2	1
'00000000964001043689359	900147	7:34:37 AM	5/12/2023 7:34	10	0.062	0	0.062	2	1
'00000000964001043689162	900147	7:37:49 AM	5/12/2023 7:37	10	0.069	0	0.069	1	1
'00000000964001043689359	900147	7:40:47 AM	5/12/2023 7:40	10	0.062	0	0.062	2	1

The SSF's GPS location is also recorded to six decimal places in latitude and longitude. This tracking capability means trends in data can be identified not only according to seasonal changes in condition, but also location. Identifying the optimum position of the SSF in the paddock could influence the reliability and effectiveness of the system.

3.4.7 Statistical analysis

Descriptive statistics have been used in this thesis to compare data across the herd and time distribution, as well as a repeated measures ANOVA (RM ANOVA) using the Jamovi package (www.jamovi.org). A null hypothesis that interaction behaviour is not significantly different was utilised, where $P < 0.05$ was considered significant. ANOVAs require a set of assumptions to be filled to maintain accuracy (Petrie & Watson, 2006), and where these are not met, modifications were made to continue the analysis. Sphericity checks were performed as assumption checks, and corrections made according to Greenhouse-Geisser (G-G) and Huynh-Feldt (H-F). To supplement the RM ANOVA, a Post Hoc Test was performed where the null hypothesis was not rejected. This test performs supplementary analysis to determine particular significance of each categorical group. Finally, to illustrate the results of statistical analysis an estimation of marginal means was completed, which

represents the mean response for each level of a factor. Greater details into the statistical methods used in this thesis has been expanded upon in the following subsections.

3.4.8 Mean, median, standard deviation and error

Key statistical measures which are frequently used to quantify animal behaviour are the arithmetic mean, median and standard deviation. Simple descriptive statistics are vital to the analysis of data which does not exhibit qualities which can easily be assessed using complex models due to their assumptions and requirements for analysis.

The arithmetic mean refers to a measure of central tendency obtained by summing all observations in a data set, to be divided by the total number of observations (Petrie & Watson, 2006). The arithmetic mean is shown in *Equation 3.1*.

$$\bar{x} = \frac{\sum x}{n} \quad [3.1]$$

Where,

x = *continuous variable of interest*

n = *number of observations in the sample*

Another frequently used measure of central tendency is the median, defined as the central value in the set of n observations which have been arranged in rank order. In other words, the median is the 50th percentile value and because the median is a set, known position in the data set, it is not influenced by outlier values (Petrie & Watson, 2006).

The standard deviation is a measure of dispersion and is equal to the square root of variance. The standard deviation may be regarded as the average deviation from the arithmetic mean within a data set and is given by *Equation 3.2* (Petrie & Watson, 2006).

$$SD = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}} \quad [3.2]$$

Where,

x = continuous variable of interest

\bar{x} = the arithmetic mean

n = number of observations in the sample

Error, or difference was calculated in this thesis using *Equation 3.3*.

$$Error = \frac{initial - final}{initial} \quad [3.3]$$

Where,

initial = the initial result

final = the result being compared against the initial result

3.4.9 Repeated Measures ANOVA

There are a variety of ANOVAs which are commonly used in the analysis of animal science, depending on the types of experiments being conducted, generally however they fit experiments where the same variable is measured repeatedly (Park et al., 2009). Common types of ANOVAs include one-way, one-way repeated measures and two-way ANOVAs (Petrie & Watson, 2006). In this case, where a single ‘treatment’ type with the independent variable of time, a one-way RM ANOVA has been utilised. When performing ANOVAs, it is important that the data set used conforms to a set of assumptions which the analysis makes, where this is not the case, modifications can be made to maintain accuracy. With the data available, and to target results relating to time of feed consumption several of the required

assumptions are not met, therefore these modifications are made and explored in the subsections below. Pre-processing of data was performed in MATLAB, while the completion of the ANOVA and associated methods has been completed in jamovi (The jamovi project, Sydney, Australia) (Love et al., 2024).

3.4.9.1 Error in repeated measures ANOVA

There are two error types which can be encountered when performing RM ANOVAs, Type I and Type II error.

Type I error encompasses to the likelihood of falsely detecting statistically significant results. This primarily occurs when there are a large number of categorical groups, with the probability of encountering false results drastically increasing after the inclusion of more than three categorical groups.

Type II error occurs when true effects are not detected and are often the result of low sample sizes and large variations in measurements.

3.4.9.2 Assumptions

The assumptions made in a RM ANOVA are outlined as follows (Muhammad, 2023).

1. The continuous dependent variable is approximately normally distributed.
2. The independent variable has three or more categorical levels.
3. No outliers are contained within the repeated measures data.
4. Data exhibits sphericity across all data.

It is noted that the data used in this analysis violates assumptions four and five of the standard RM ANOVA, therefore, corrections were enforced to minimise Type I error. Type II error was avoided due to the significant sample size ($n = 73$) of this trial.

3.4.9.3 Mauchly's Test

To identify whether sphericity is reasonable the Mauchly Test can be completed (Mauchly, 1940). Mauchly's test is deemed significant where the p-value is less than 0.05 and therefore the assumption of sphericity is violated. Where this occurs, spherical corrections are applied through jamovi.

3.4.9.4 Sphericity Corrections: Greenhouse-Giesser and Huynh-Feldt

Where data does not demonstrate sphericity, corrections are made through modifiers such as the G-G and H-F modifiers. G-G sphericity corrections are better suited to scenarios with significant violations in sphericity, while the H-F method is better suited in other cases as it is less conservative (Huynh & Feldt, 1976; Singh et al., 2013). These corrections have been applied where relevant within the jamovi software package.

3.4.9.5 Post Hoc Tests

Post Hoc tests are a method of multiple comparisons, and are used to isolate specific categories of a RM ANOVA to compute their comparative significance (Park et al., 2009). There are four types of Post Hoc tests available for use within the jamovi software, including, Tukey Honest Significance Difference (HSD), Scheffe Test, Bonferroni Correction and the Holm-Bonferroni Method, where these adjust for multiple comparisons through varying methods. The HSD test is ideally used in cases of equal sample size and variance, effectively controlling Type I error (Agbangba et al., 2024). The Schaffe test is flexible and conservative, controlling family wise error across all possible comparisons (Agbangba et al., 2024). This method is suitable for samples of unequal size however increases Type II error more than other methods. The Bonferroni Correction is considered more conservative, and divides significance by the number of comparisons, reducing Type

I error risk to the detriment of increasing Type II error (Agbangba et al., 2024). A modified Bonferroni Correction, the Holm-Bonferroni method and is generally considered to be superior in power while maintaining family wise error rate (Agbangba et al., 2024).

Due to the nature of the experimental trial conducted in this thesis (uniform sample size, a large number of family categories (comparisons with time) and significant variance within the RM ANOVA), two Post Hoc tests were performed. Tukey's HSD and Holm-Bonferroni both have robustness against variance, especially with large sample sizes and complement each other in the former's capacity to compare multiple categories and the latter's dynamic adjustment for significance (Agbangba et al., 2024). Combined and where aligned, these should powerfully control Type I error within the experiment.

3.4.9.6 Estimated Marginal Means

To supplement the result of the RM ANOVA a summary of Estimated Marginal Means (EMM) was produced using the jamovi software. EMMs provide the adjusted average responses post modification through Post Hoc tests and sphericity corrections. This provides a more accurate representation of true means rather than those produced from raw averages.

3.4.1 Summary of MATLAB functions

MATLAB functions have been used to ensure the reliable import of raw data across a range of script files during data analysis. These functions have been generated using the MATLAB import wizard and were modified to suit the requirements of this project. All used functions have been collated in Appendix E.

3.4.1.1 Equip Location

Imports equipment location data from the SSF. This is a single file with three columns of data, relating to date, latitude and longitude. Date data is imported as a string while location data is imported as doubles.

3.4.1.2 MooMonitor Data

Imports animal behavioural data collected from MooMonitor+ collars. There are three files containing such data, which includes cow identification, date, behaviour type and time spent doing each activity. Data was collected in 15-minute intervals and daily totals were included. Data has primarily been imported as doubles, however date and behaviour recordings have been accessed as strings.

3.4.1.3 Intake Mass Data

Intake mass data was imported from a single file, which records animal intake with ID, time and tray. From the data formatting, tray identification and date/time data have been imported as strings, while all other data was imported as doubles.

3.4.1.4 RFID Data

The RFID data recorded in trial contains the “InorOut” condition of animals interacting with the feeder, arranged by time of interaction and animal ID. The tray which the animal was interacting with is also available. Time and InorOut condition have been imported as strings, while cow tag and tray identification have been imported at doubles.

3.4.1.5 SSF Data 2

Additional information pertaining to intake mass was recorded in an additional file, this contains some information which was already available from intake mass data, however,

supplements it with more specific timing, mass delivery and remainder, feed type and flag messages in the result of errors. Date/Time and flag information have been imported as strings, with all other data imported as doubles.

3.4.2 Summary of MATLAB scripts

MATLAB scripts have been used in this thesis to process, filter, analyse, store and present the data imported from function files. All mentioned scripts have been collated in Appendix E.

3.4.2.1 Animal Mass Intake Herd Individual

The purpose of this script is to plot individual and herd averaged mass intakes over the course of the trial period. Plots are produced for individual animals as well as the average herd. All figures are saved for storage and review.

3.4.2.2 Average Herd MooMonitor Plotting

The purpose of this script is to plot average herd daily total rumination, resting and feeding behaviour. All available MooMonitor+ data is imported and behavioural plots for individual animals and the overall herd are produced, all of which is saved in the relevant directory.

3.4.2.3 Daily MooMonitor Behaviour

This script incorporates all available MooMonitor+ data to identify daily behavioural characteristics for the herd. Results are divided into monthly intervals, as well as a general plot encompassing behaviour over the entire trial period.

3.4.2.4 Data Validation

All used data files are imported into MATLAB and individually checked for missing data. This was performed to ensure that the functions created for data importation do not lose data.

3.4.2.5 Equipment Heatmap

This script creates a heatmap illustrating the movement of the SSF over the course of the trial period. Location data is superimposed over a satellite basemap, marking the region of interest and illustrating herd movement.

3.4.2.6 Cropped Delivery Accuracy

Identifying the accuracy of mass delivered to each animal this script used mass delivery data which was cropped between the bounds of 23 January 2024 and 16 February 2024. These bounds represent a stable period of data where mass delivery is at specification and no other factors are causing inconsistencies. Statistics and figures relating to delivery accuracy are produced.

3.4.2.7 Individual MooMonitor Plotting

With the same method of Average_MooMonitor_Plotting, this script iterates the process for each individual animal within the herd. All figures are saved in a relevant location for further review.

3.4.2.8 Interaction Statistics & Interaction Statistics 2

These scripts are used to identify key hourly interaction statistics relating to interactions at the SSF, including individual interaction plots for each animal. Tabulated results are saved for further analysis, including RM ANOVA. Overall herd results are plotted, and key descriptive statistics are calculated.

3.4.2.9 Mass Intake Statistics

The purpose of this script is to identify key statistics relating to intake mass, specifically with relation to individual tray performance. Comparison plots are created for feeder trays and delivery accuracy.

3.4.2.10 Scan Times

This script utilises RFID data to determine the interaction frequency of individual animals. Data is combined across the trial period and key comparison plots are prepared.

3.4.2.11 Simultaneous Interactions

Utilising intake data, an alternative method for identifying scan times is implemented. Key interaction statistics are extracted for discussion alongside prepared figures.

3.4.2.12 SSF Malfunction Analysis

This script used intake data to determine the impact of a systems malfunction on animal feed interactions at the SSF. This is achieved by dividing the data into pre-, during and post-malfunction scenarios. Key figures are produced, and results saved for review and documentation.

3.4.2.13 Tray Interactions

The purpose of this script is to determine the mass delivery intervals and quantities at each feeder tray. This is performed using two different data sets with results saved in the relevant location and plotted for review.

3.5 RISK MANAGEMENT

A risk assessment was prepared for the purpose of this dissertation to ensure the effective management of risks associated with this project. The assessment was organised in the form of a Risk Management Plan, RMP, which assesses the likelihood and consequence of hazards, where a risk is defined as the product of these two factors.

Risks may affect equipment, the risk taker, related parties, and data security, where the RMP aims to minimise the effect of negative risk. The RMP written for this project was attached in Appendix D.

3.6 PROJECT TIMELINE

A Gantt chart was constructed during the project planning and specification of this project, this was attached in Appendix F. Gantt charts are a useful project management tool which provide a visual representation of project milestones and their expected completion times. This timeline was completed using Microsoft Excel, including expected activities and flow of the project path.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 INITIAL ANALYSIS OF THE EXPERIMENTAL DATA

An initial analysis was performed to gauge the quality and usability of the behavioural data provided. Raw data was processed in MATLAB to determine the average mass intake of the herd, with the outcome of this process illustrated in *Figure 4.1*. Initial impressions suggested a long training period where the animals acclimatise to the supplementary feed provided by the SSF, after which some stability was achieved. This figure also depicts periods where the SSF has clearly run out of feed and none of the animals have received their daily allocation.

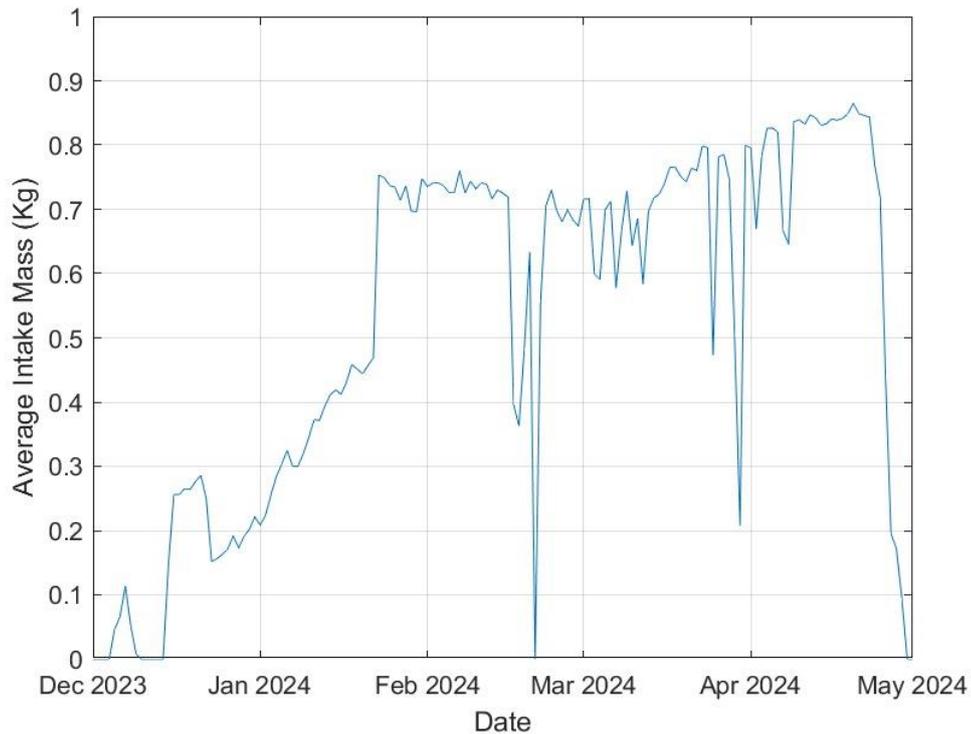


Figure 4.1: Average herd mass intake at the SSF between December 2023 and May 2024.

Upon investigations into the individual animal data however it was evident that many animals interacted reliably with the SSF, and quickly became accustomed to its presence.

An example of this is illustrated in *Figure 4.2* from the intake mass data, where cow 2201 can be seen to quickly learn to use the SSF daily.

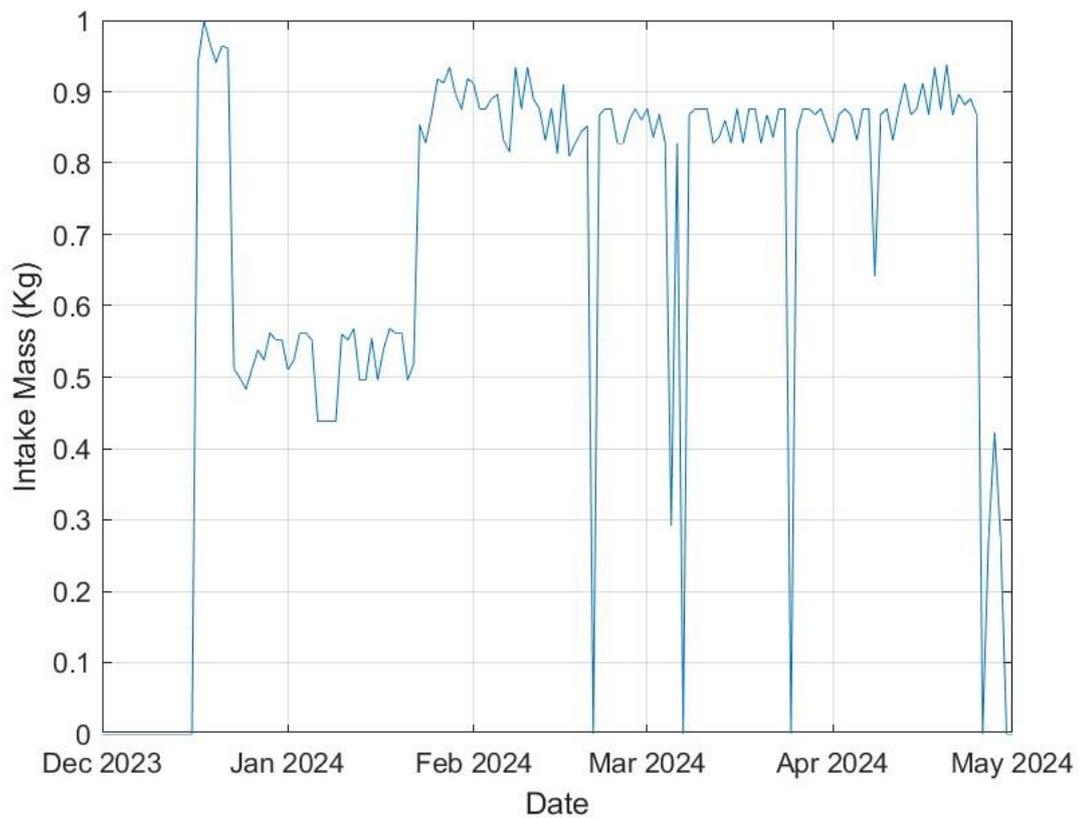


Figure 4.2: Intake mass for cow 2201 between December 2023 and May 2024.

During the initial training period, approximately 0.9-1 kg of feed was made available for the animals to consume. This was followed by a month-long period where 0.4-0.5 kg was provided, after which a sustained level of 0.8-0.9 kg was introduced from January 26. These quantities are approximate due to the method of feed delivery utilised by the SSF. An excerpt of intake behaviour for each individual animal is compiled in Appendix G. The feeder system determines supplement delivery based on the duration and number of intervals. For example, when an animal with remaining daily feed allocation is identified, the SSF delivers

10 seconds of feed at a calibrated rate. Once the feed is consumed, and if the animal still has more allocation left to be consumed, another 10-second interval is initiated.

This interval-based approach, rather than measured mass delivery, introduces random errors in the total feed provided. These discrepancies vary depending on the type of feed being delivered. In the trial at TDRF, pelletised feed was used for the heifers, which can clump or degrade when exposed to moisture due to their water soluble DM content (Cozzi et al., 2002). While pelletised feed generally has uniform density and volume, moisture can affect this consistency. In a system where feed delivery is calibrated by intervals, such irregularities reduce the accuracy of feed distribution (Byron, 2018; Ziegler, 2020). Furthermore, each feeder tray is calibrated individually, which, while preventing systematic errors occurring as a result of a single calibration, prevents the exact uniformity of feed delivery across trays.

The most significant variations in feed delivery were found to occur when animals move between trays, consuming feed from multiple sources, each with slightly different calibrations. This is observable in the intake data, see *Section 4.5 Accuracy of mass delivery*, which affirms the movement of cattle around the feeder trailer while feeding. This effect was observed in previous thesis research of the similar GreenFeed system, where it was identified that ‘cup drops’ lack uniformity in mass delivery (Byron, 2018; Ziegler, 2020), while not identified with the SSF, these systems utilise the same delivery mechanism. From cow 2201, consumption of these feed values oscillates daily; it can also be seen that mass intake occasionally exceeds these maximum feed values. This can likely be attributed to delivery variations discussed above, as well as to the SSF distributing feed using a belt conveyor, which has limited accuracy as a reactive system in contrast with a proactive one.

There are 11 animals which interacted poorly with the SSF system. This could be due to a variety of factors. For example, animal 2212 exhibits almost zero interaction with the SSF as seen in *Figure 4.3*, while other animals such as 2263, shown in *Figure 4.4*, do not begin interacting until far later in the trial period, and therefore negatively influence the majority of the herd averaged data. To prevent this from impacting later analysis of the SSF data, animals such as these were filtered, either for removal or to include only some of their interaction data. This is a further limitation of this study which is discussed in *Section 4.7 Challenges encountered and limitations of the study*.

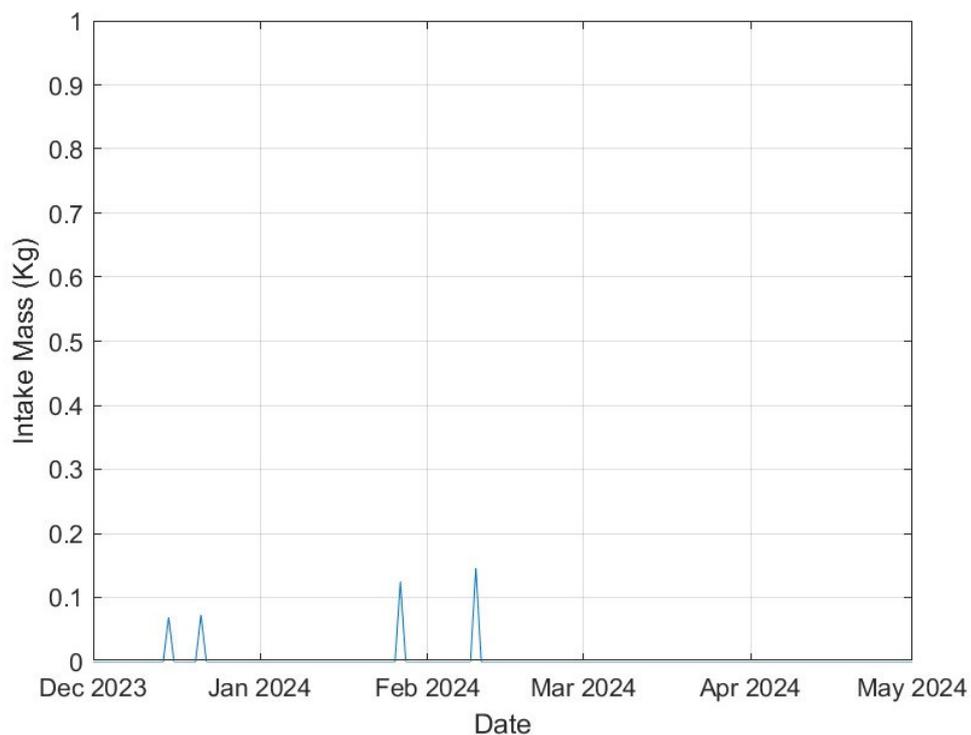


Figure 4.3: Intake mass for cow 2212 between December 2023 and May 2024.

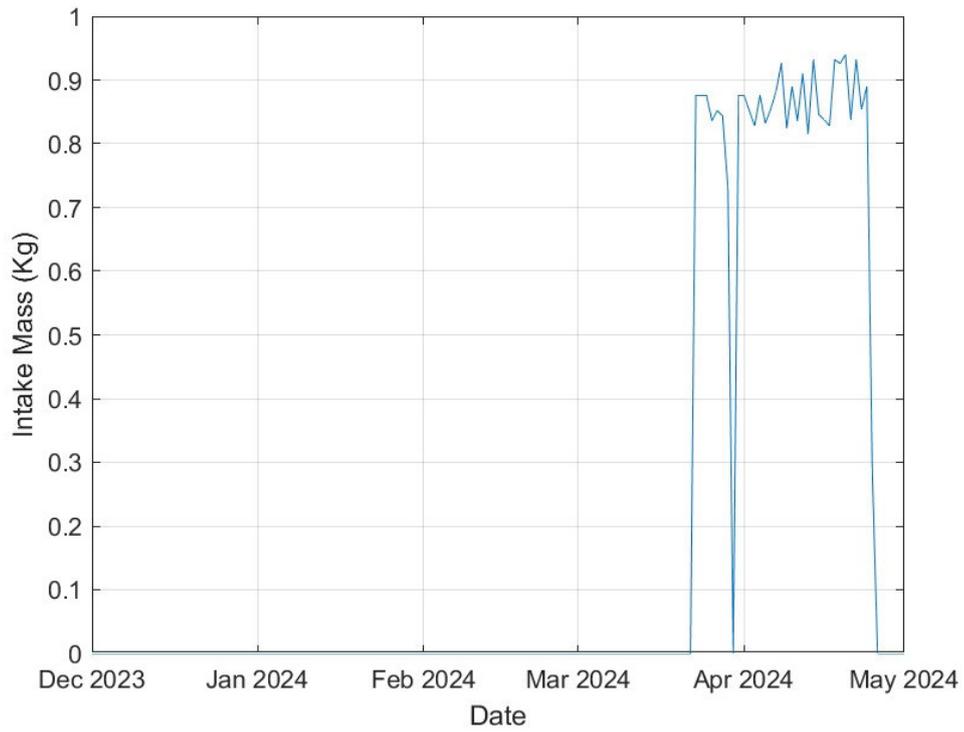


Figure 4.4: Intake mass for cow 2263 between December 2023 and May 2024.

Taking these 11 outlying cows into account, the remainder of the herd interacts with the SmartFeed trailer according to *Figure 4.5*.

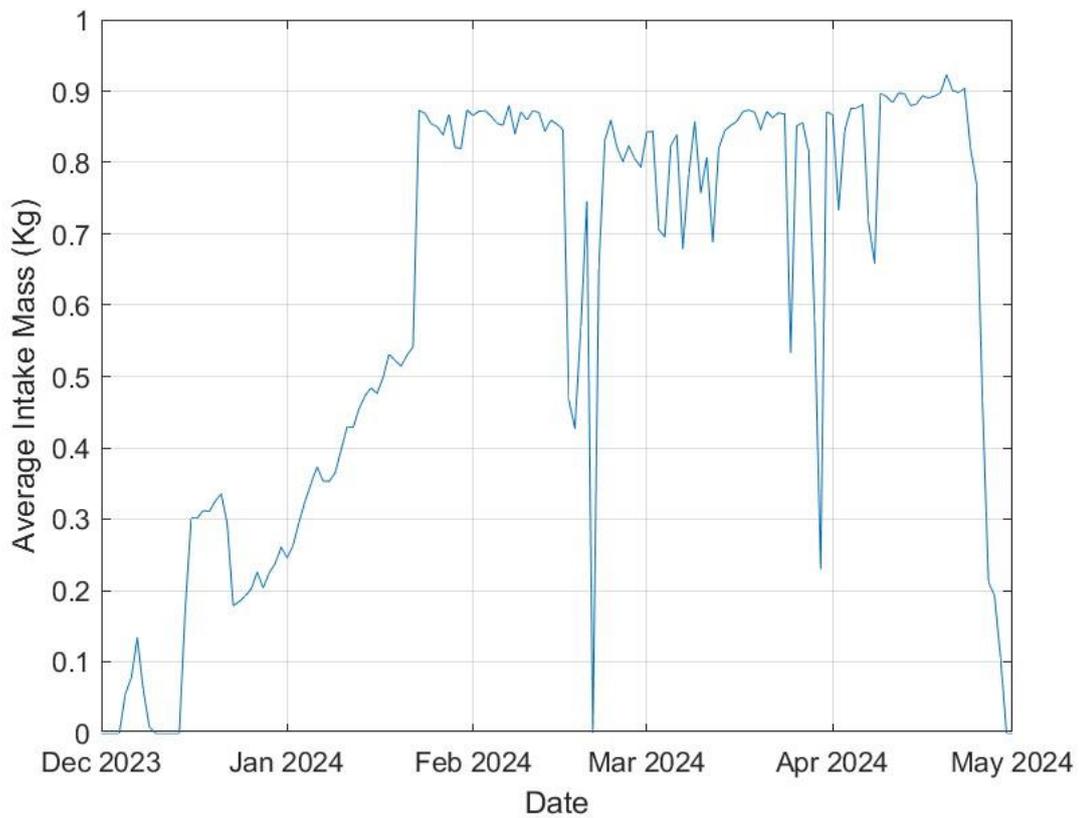


Figure 4.5: Average herd mass intake at the SSF between December 2023 and May 2024 with 11 of the poorly performing animals removed from the dataset.

In addition to SSF data, results from the MooMonitor+ collars were also analysed. Within this data set, each animal’s behavioural trends have been categorised into the three main functions of a ruminant; ruminating, resting and feeding. The herd averaged data seen in *Figure 4.6* was compiled from the average of individual animal’s daily totals. MooMonitor+ collar data has been provided one month prior to the introduction of the SSF. A more detailed excerpt of individual animal MooMonitor+ behaviour is located in Appendix G.

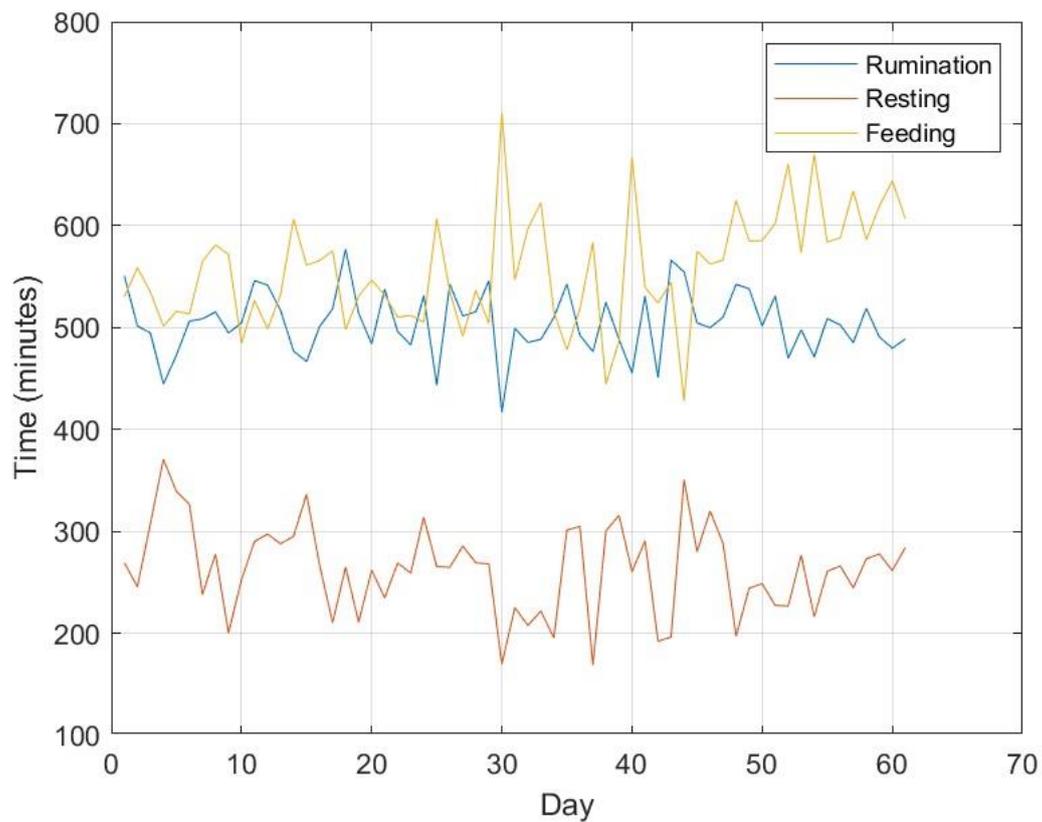


Figure 4.6: Herd averaged behaviour during November and December 2023.

It is immediately clear from *Figure 4.6* that cattle spent most of their time grazing, and the least resting, while not directly mentioned, this result falls within the findings of an invited review of cattle behavioural patterns (Beauchemin, 2018). In this paper it is identified from a meta-analysis of multiple studies that the behavioural patterns of cattle are influenced by a wide range of factors, with some studies reporting more time spent ruminating than feeding or the opposite. For animals in a forage-based system it is reasonable that time spent feeding is greater than that spent ruminating. Resting time largely ranges between 200 and 300 minutes per day, or ~3-5 hours. Animals appeared to spend more time feeding and less ruminating moving into January. When considering this figure in comparison with *Figure 4.2*, it can be hypothesised that the reduced time spent ruminating is linked with increased

consumption at the feeder station on average by the herd. This hypothesis is supported by other study findings in which they identified that pelletised feed sources reduced rumination time compared to forages (De Boever et al., 1990; Welch, 1982). A numeric comparison of herd behavioural trends has been investigated in *Section 4.4 Animal behaviour around the SSF*.

4.2 TIME OF ANIMAL INTERACTION WITH THE SUPER SMARTFEED TRAILER

A key indicator of viability for the delivery of methane mitigating supplements to cattle in grassfed systems, is when they consume their allocated feed supplement relative to their consumption of pasture.

Identifying when animals interact with the SSF was achieved by collating daily interaction data for individual animals into hour long periods, where the frequency of interaction in each period was then compared. While each animal interacted uniquely with the SSF, common trends among the animals are illustrated in *Figure 4.7*, *Figure 4.8* and *Figure 4.9*, while a more extensive excerpt is located in Appendix G. These figures represent ~150 days of interaction data, where each interaction is an individual feed event at the SSF system.

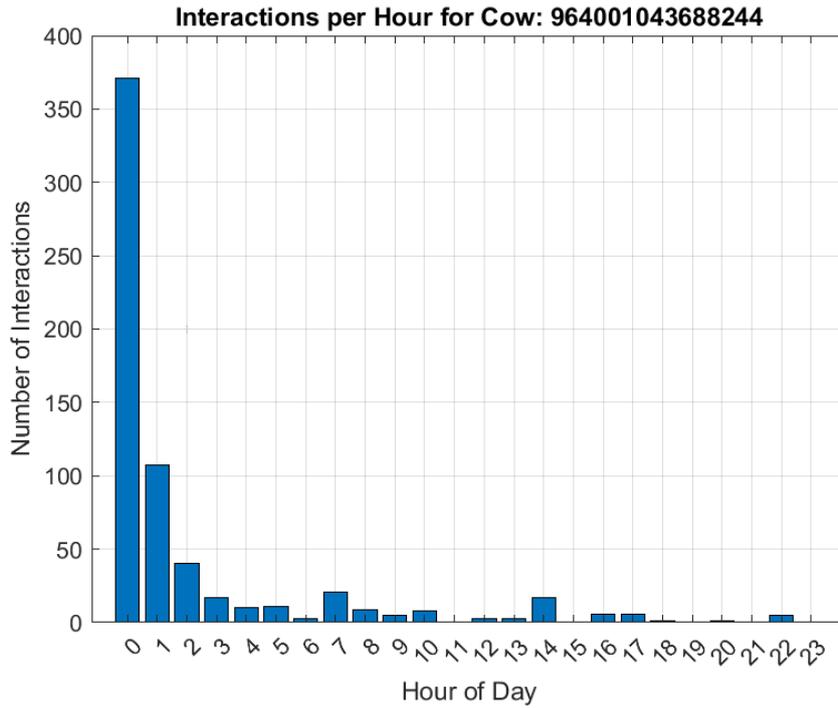


Figure 4.7: Behaviour of an animal with strong interaction early in the day.

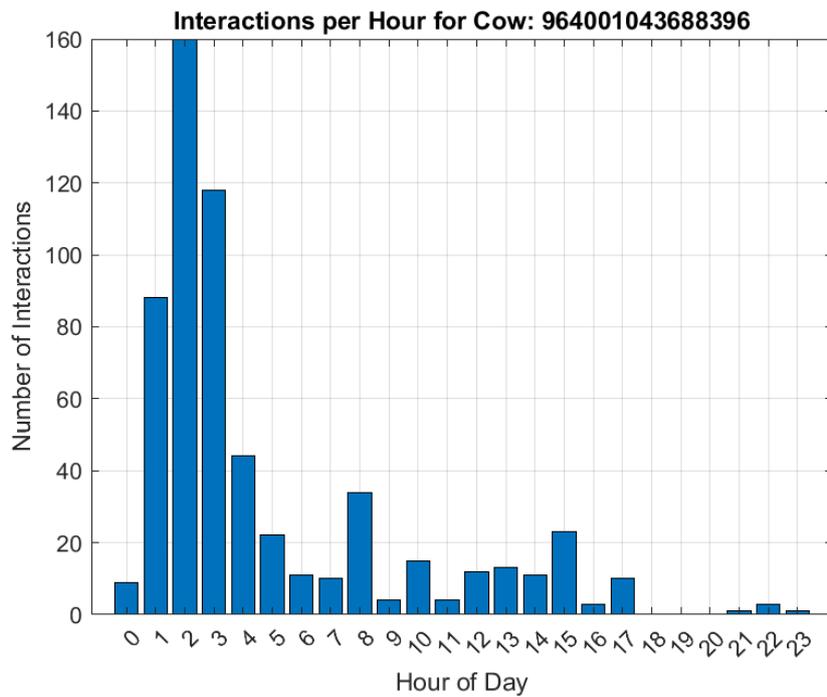


Figure 4.8: Behaviour of an animal with moderate interaction early in the day.

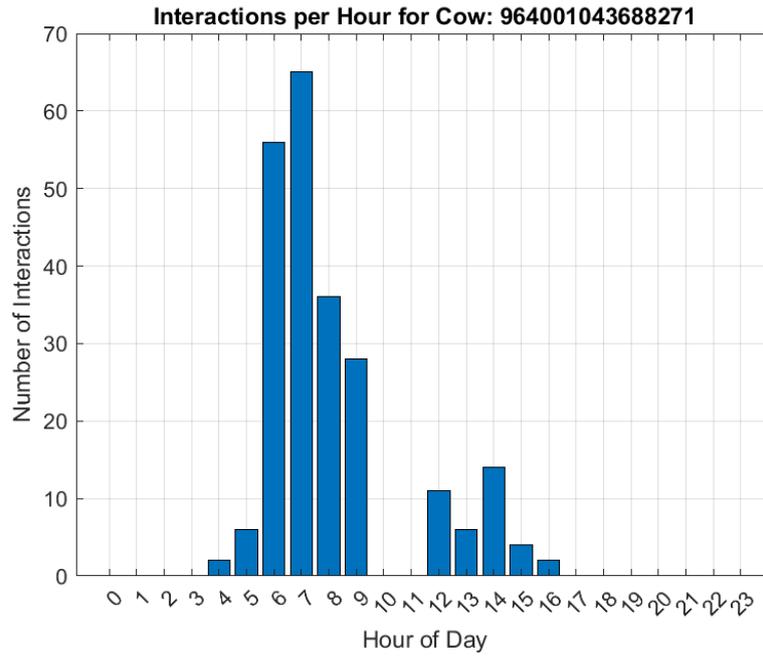


Figure 4.9: Behaviour of an animal with weak interaction during the day.

The combined interaction data was collated and compared for key statistical measures of mean, median and standard deviation at each hour long increment of a day. These results have been summarised in *Table 4.1*, and illustrated by a box and whisker plot in *Figure 4.10*. The individual animal data such as that exhibited in *Figure 4.7*, *Figure 4.8* and *Figure 4.9* which is used to compile these results has been attached in Appendix G for further context.

Table 4.1: Frequency of interaction events among the entire herd over a 156-day period.

Row	Mean	Median	Standard Deviation	Min	Max
Hour_1	159.63	60	171.87	0	530
Hour_2	101.66	100	69.67	0	261
Hour_3	73.79	60	51.66	0	189
Hour_4	51.36	42	40.24	0	142
Hour_5	25.38	13	30.27	0	133
Hour_6	32.34	24	29.33	0	145
Hour_7	32.34	27	27.07	1	148
Hour_8	21.29	17	16.65	0	75
Hour_9	13.51	12	10.28	0	46
Hour_10	9.44	8	8.59	0	29
Hour_11	8.99	7	7.50	0	26
Hour_12	5.89	6	5.42	0	21
Hour_13	7.10	6	6.30	0	28
Hour_14	10.19	8	10.07	0	63
Hour_15	9.89	9	7.24	0	28
Hour_16	5.97	6	5.32	0	23
Hour_17	5.74	6	5.21	0	24
Hour_18	4.52	3	5.12	0	22
Hour_19	3.40	1	4.21	0	15
Hour_20	3.93	2	4.79	0	21
Hour_21	4.19	2	5.11	0	22
Hour_22	2.37	1	3.37	0	15
Hour_23	1.81	0	3.11	0	17
Hour_24	3.05	2	3.93	0	16

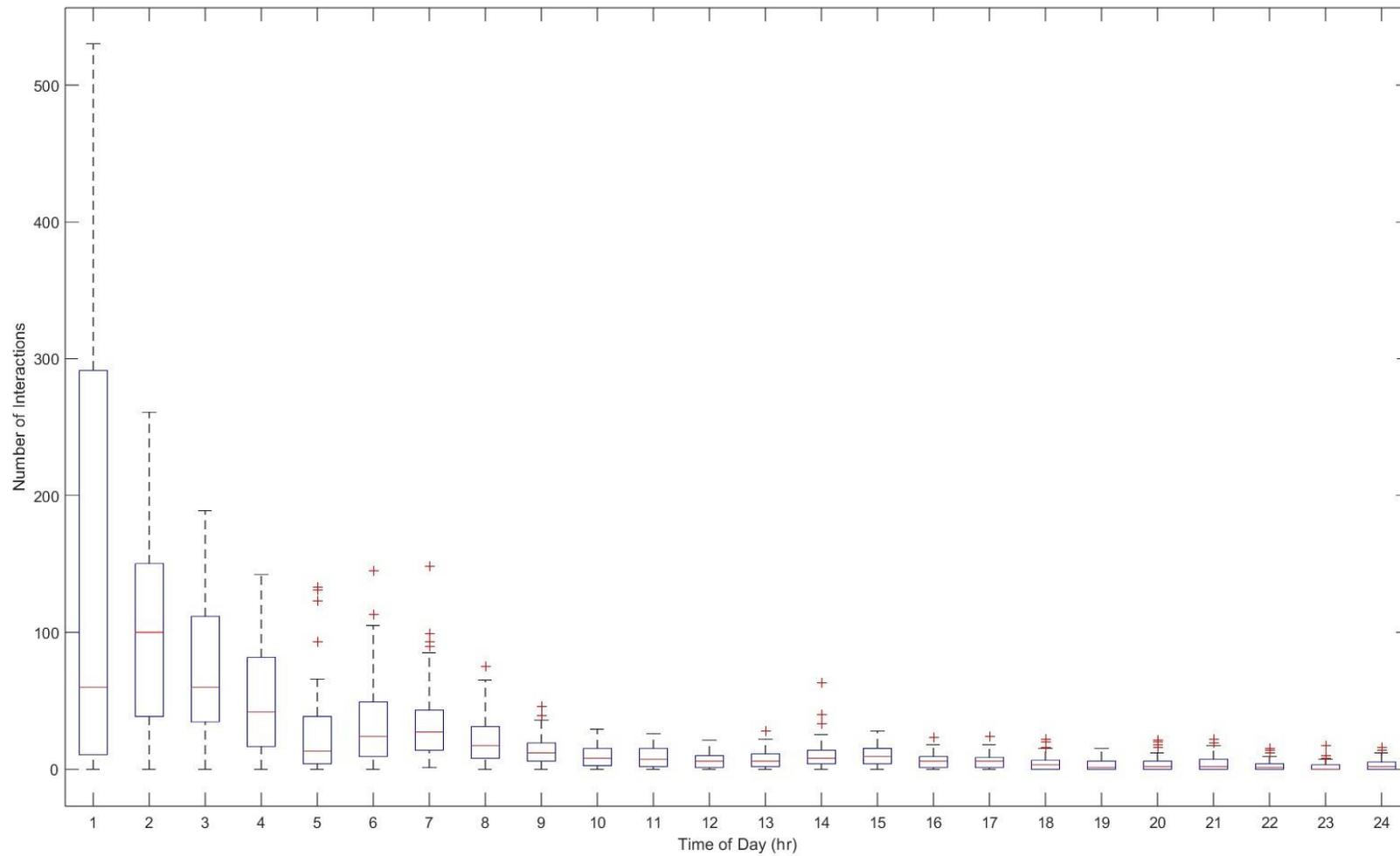


Figure 4.10: Box and whisker plot of accumulated time of day interactions during from the entire study period, ranging between December 2023 and May 2024.

The results of this analysis demonstrate clearly that most herd interactions with the SSF occur in the early hours of the morning, with 68.89% of animals consuming their feed within the first four hours of feed becoming available. The SSF resets its daily allocation of feed at midnight, indicating that animals recognise and remember when feed becomes available for consumption during the day, while actively engaging with the system at this time. The capacity for animal memory and learning indicated in this trial provides further opportunity for modification and training around the SSF system in future studies.

There is a considerable deviation in mean and median interactions in the early hours of the morning, indicating that a select few animals actively engage the SSF vigorously, and only after these animals have moved away does the main herd interact. This is illustrated in *Figure 4.10* by a steady decrease in mean interactions while median interactions increase by 40 interactions/hr after 01:00. The animals which interact first with the smart feeder are those which are dominant among the herd, these animals exist high in the herd hierarchy and therefore push forward to receive their feed allocation. This behaviour has been observed in automatic milking parlours and in grazing operations delivering supplements through ground fed lines and piles (Bica et al., 2019; Lauwere et al., 1996).

Based on the behaviour observed in these papers and this thesis, animals which interact with the feeder poorly, such as in *Figure 4.9* are likely to have low standing amongst the herd hierarchy and are excluded from feeding with the main herd. This explains why some animals do not interact with the system at all, as cattle exhibit herd behaviour, with animals grazing, moving and interacting at the feeder at similar times. Once the majority of the herd is finished at the feeder, the entire herd moves on, including those who were excluded.

To further support the interaction behaviour of animals with the SSF a RM ANOVA was performed (*Table 4.2*).

Table 4.2: RM ANOVA summary for hourly interactions.

Within Subjects Effects							
	Sphericity Correction	Sum of Squares	df	Mean Square	F	p	η^2_p
Hour of the Day	None	2.41e+6	23	104708	59.7	< .001	0.453
	Greenhouse-Geisser	2.41e+6	1.67	1.45e+6	59.7	< .001	0.453
	Huynh-Feldt	2.41e+6	1.70	1.42e+6	59.7	< .001	0.453
Residual	None	2.91e+6	1656	1754			
	Greenhouse-Geisser	2.91e+6	119.95	24221			
	Huynh-Feldt	2.91e+6	122.45	23727			

Note. Type 3 Sums of Squares

The results showed that hour of the day had a significant influence on animal interaction behaviour with the SSF ($p < 0.001$).

Testing for sphericity was achieved by using Mauchly's W, where $p < 0.001$, suggested significant departure from sphericity. To adjust the ANOVA to suit this scenario the G-G correction method was applied on favour of H-F, with a conservative correction of $\epsilon = 0.0724$ (*Table 4.3*), providing a major adjustment.

Table 4.3: Summary of tests for sphericity.

Tests of Sphericity				
	Mauchly's W	p	Greenhouse-Geisser ϵ	Huynh-Feldt ϵ
Hour of the Day	1.30e-31	< .001	0.0724	0.0739

To identify the significance of individual hours within the day, Post Hoc tests were performed (Appendix H). From these tests, using both Tukey's HSD and the Holm-Bonferroni it was identified that there was little to no significant difference between adjacent hours, when considering frequency of feeder interactions. This reliable progression of significance ($p < 0.05$) with hourly interactions, confirms the skewed nature of hourly interactions, which taper away significantly over the progression of the day.

EMM has been illustrated in *Figure 4.11*, showing the mean adjustments used in the RM ANOVA when assessing hourly interaction behaviour. The EMM exhibits the true effects relating to hourly interaction behaviour differently to the portrayal of raw effects in *Figure 4.10*. For the animals interacting with the SSF, interaction behaviour is skewed towards the early morning, where the SSF resets and a new allocation of feed becomes available.

Hour of the Day

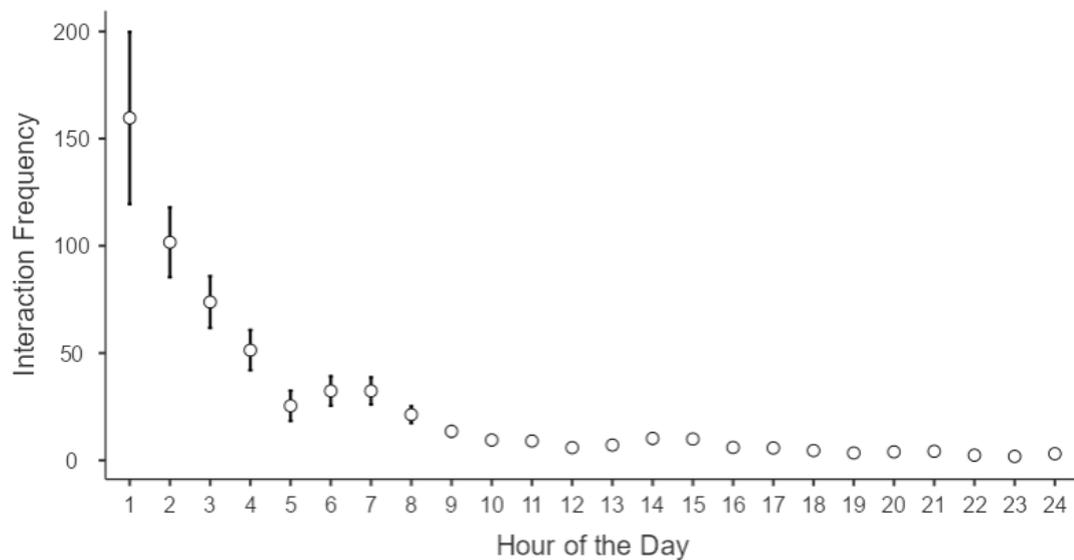


Figure 4.11: EMM for hourly interaction frequency.

The results of this analysis also indicate that while the majority of feeder interactions occur immediately after feed becomes available, animals still interact with the system throughout the remainder of the day. This also shows that interaction with the feeder system stabilises to under an average of 10 interactions per hour after 10:00 over the 156-day period.

The tendency of the heifers to interact with the SSF immediately after feed becomes available provides opportunity for graziers to control when the animals consume feed supplements by manipulating when feed becomes available at the feeder. This is promising as the behaviour can be manipulated, giving viability to the potential practice of delivering multiple doses of methane mitigating supplements to cattle during the day. By spreading these supplements into multiple doses throughout the day, methane mitigating compounds can remain in the animal's digestive system, thus maximising the efficacy of using methane mitigating feed. Future experimentation with multiple feeding occurrences over the course of a day, targeted for pre-feeding the diurnal grazing patterns of cattle would be beneficial to further ascertain the exact viability for delivering methane mitigating supplements to grazing cattle.

These findings have found that to maximise animal interactions with the SSF system during these interaction periods it may prove beneficial to utilise multiple feeding stations which are located separately. This may provide greater opportunity for animals which traditionally have a low-standing in-herd hierarchy to consume supplementary feed with less competition than at a single feeder. This concept is supported by research identifying increased variability in supplement intake depending on feed competition and animal dominance (Grant & Albright, 2001).

4.3 SIMULTANEOUS INTERACTION BEHAVIOUR

As previously explored, cattle are herd animals which exhibit hierarchical interaction behaviour. Understanding how many animals interact with the feeder system simultaneously is therefore vital in determining how their behavioural tendencies influence feed intake. For the purpose of analysing interaction frequency, simultaneous interactions have been defined as the number of unique animals which interact with the SSF within a minute long window. By this definition, interaction frequencies have been divided and are compiled in *Table 4.4*.

Table 4.4: Simultaneous interaction behaviour across entire trial.

Number of animals interacting	Number of event occurrences	Percentage of event occurrences as a function of all events
1	19065	67.55%
2	6776	24.01%
3	2020	7.16%
4	346	1.23%
5	14	0.05%
6	1	0.00%

These results identified that the majority of feeding events occurred with a single animal interacting at a time, representing 67.55% of all interactions with the SSF. The remaining interactions mainly occur with two and three animals interacting within a one-minute window, representing 24.01% and 7.19% of feeding events respectively. Occurrences of four or more animals interacting with the SSF simultaneously are exceedingly rare, representing just 1.28% of all interactions combined.

The implication of this analysis is that animals interact with the SSF individually more than they do as a herd. Simultaneous interactions occur in the early hours of the morning when feed is freely available, however after the initial feeding period the majority of animals interact individually, this has been illustrated in *Figure 4.12*.

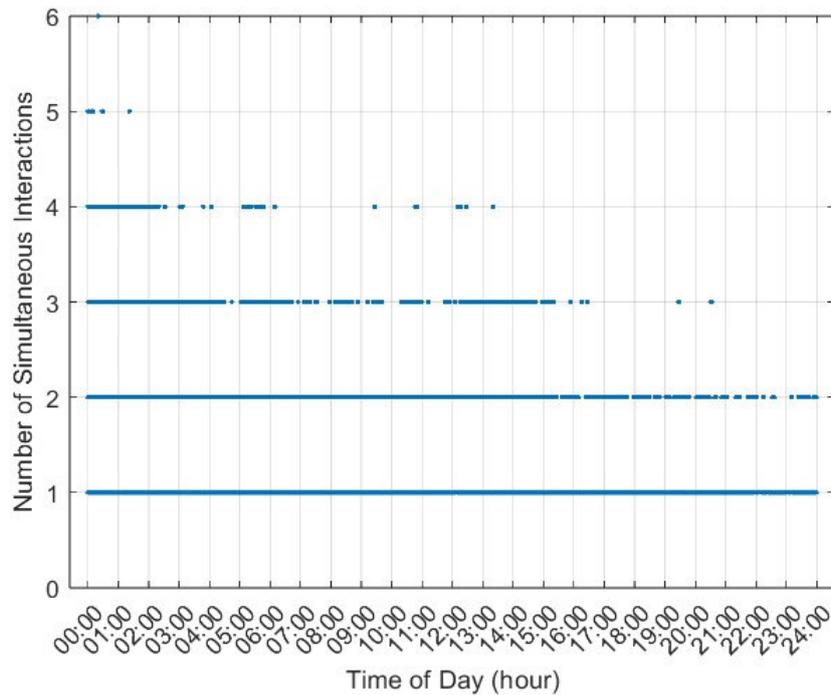


Figure 4.12: Number of animals interacting with the SSF across a daylong period.

It can also be identified that 98.72% of the time, when an animal is interacting with the SSF there is at least one other tray available for them to investigate. This has relevance for system redundancy in the event of a malfunction while also granting animals choice to move and ‘graze’ the feeder. Larger herd sizes would likely see increases in simultaneous interaction behaviour around the SSF and it is probable that the optimum herd size for a four bale SSF could be determined in future work.

4.4 ANIMAL BEHAVIOUR AROUND THE SSF

A significant component of optimising the delivery of methane mitigating supplements to grazing animals is targeting their behavioural patterns with feed delivery timing. The

MooMonitor+ collar data collected one month prior and over the course of this study allows this to be done. Comparison of rumination, resting and feeding behaviour have therefore been drawn prior to and during the experimental trial of the SSF with the 2-year-old dairy heifers, where the cumulated daily behavioural patterns across the entire trial duration have been illustrated in *Figure 4.13*. (Where no behaviour was determined by the MooMonitor+ collars, missing time has been denoted ‘Miscellaneous’).

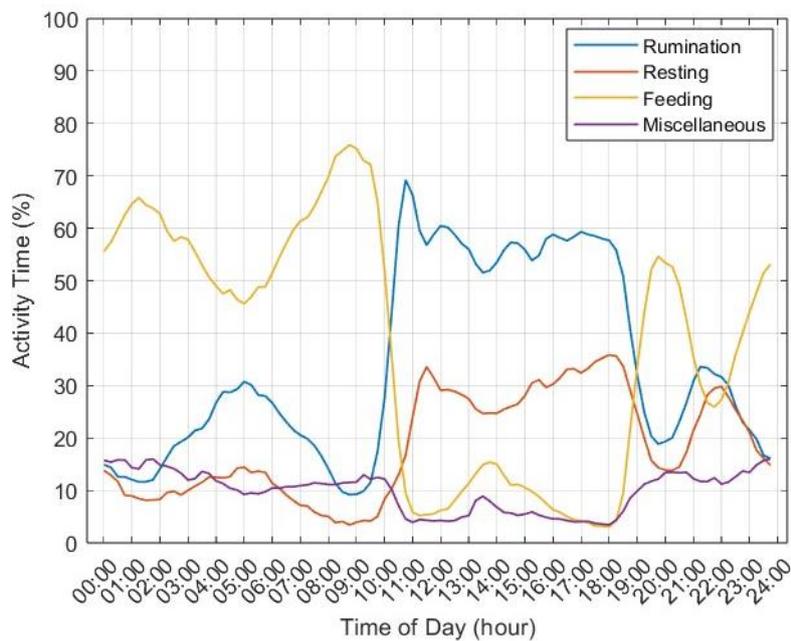


Figure 4.13: Cumulated daily herd averaged behaviour, where activity time is expressed as a percentage of time available.

Across the trial period, herd feeding behaviour experienced three peaks throughout a hypothetical day, at approximately 01:00, 09:00 and 20:00. Proportion of time spent feeding was found to be greatest in the morning, with generally more than 50% of the herd’s time spent consuming feed between midnight and 10:00. Feeding behaviour reduces significantly between 10:00 and 18:30, and the animals use this time primarily to ruminate, which dominates just under 60% of their time during this period, time spent resting also increases

by approximately 20%. Rumination primarily occurs between 10:00 and 19:00, where it is the primary activity during this time, taking up 60% of all activity. Methane is primarily produced during rumination due to supplement modes of action and this time-period is therefore a valuable target for the timing of supplement delivery (Hegarty et al., 2021). *Figure 4.14* illustrates the changes in behavioural patterns amongst the herd prior to and after acclimatisation with the SSF. The month of January was compared as all data is available and feed intake at the SSF has stabilised.

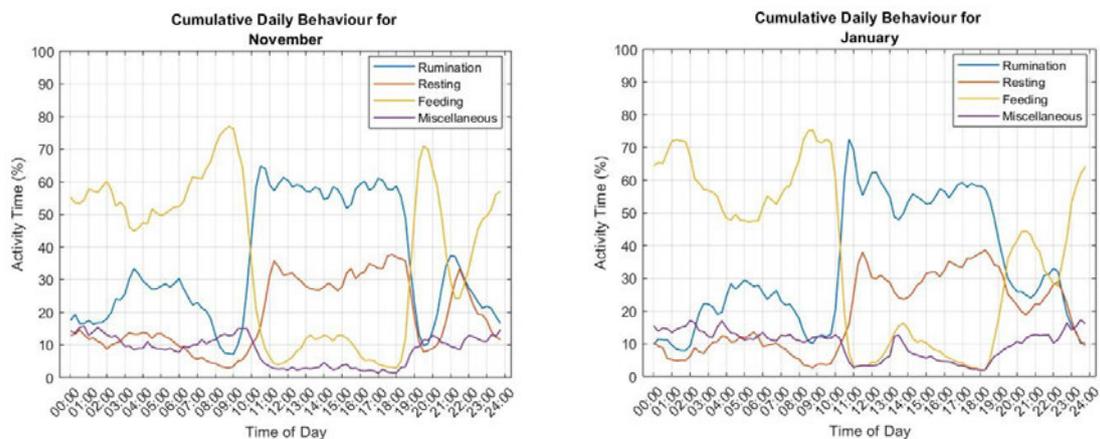


Figure 4.14: Comparison of herd behaviour prior to SSF introduction and after acclimatisation period.

Key areas of comparison revolve around an estimated 10% increase in time spent feeding between the hours of 01:00 and 02:00, which is counterbalanced by a ~25% reduction in time spent feeding at dusk. Additionally, a spike in rumination behaviour is evident after feeding concludes after 10:00, with slightly reduced rumination behaviour after this point.

Error within the MooMonitor+ collar data influences the accuracy of comparisons which can be drawn. There are 1440 minutes in a day, where the proportion of missing data within ‘Miscellaneous’ is that which cannot be categorised. A comparison of categorisation error

within each month of data recording has been summarised based on descriptive statistics in *Table 4.5* as a measure of time over a 1440-minute (one-day) period.

Table 4.5: Herd averaged daily behaviour durations.

	Month				
	Nov	Dec	Jan	Feb	Mar
Rumination	485.44	455.86	399.90	505.63	504.04
Resting	272.15	284.11	231.96	272.32	255.55
Feeding	556.51	521.13	409.17	546.14	575.42
Miscellaneous	125.90	178.90	398.96	115.91	104.99
Error	8.74%	12.42%	27.71%	8.05%	7.29%

Generally, error remains close to 10% which has a minimal impact on results, however in the month of January this jumps to 27.71%, as illustrated in *Figure 4.15*.

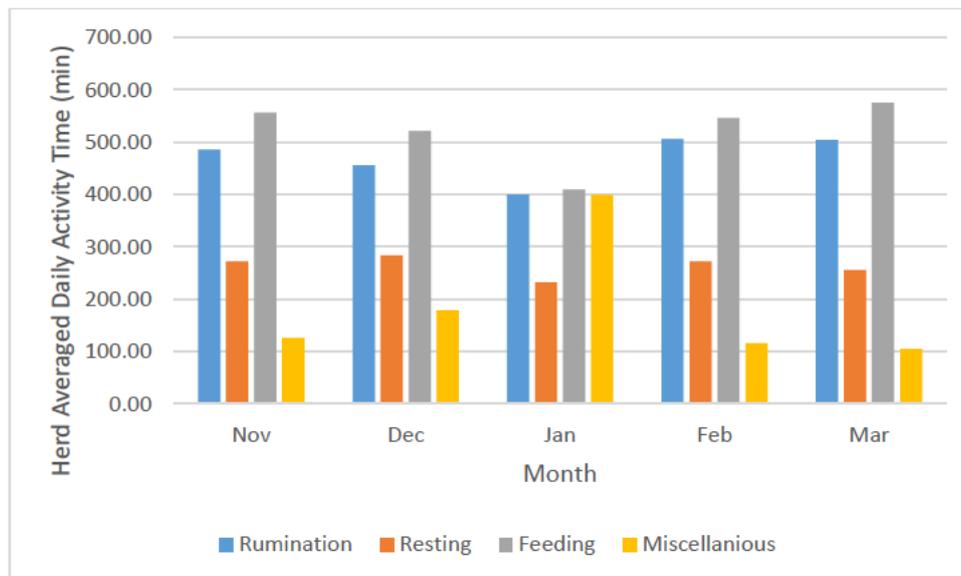


Figure 4.15: Herd averaged daily behaviour durations.

From *Table 4.5* and ignoring the month of January due to the spike in miscellaneous error, feeding time appears to increase by approximately six-minutes per month while rumination time increases by approximately eight-minutes per month.

Considering the accuracy of the MooMonitor+ collars as identified using RumiWatch halters (Werner et al., 2019) it is proposed that these increases in behaviour are related to animal growth, rather than the hypothesised increased consumption at the SSF. If consumption at the SSF was influencing rumination and feeding behaviour it would be expected that these behaviours would plateau, correlating with the stability of feed delivery at the SSF. This has not been observed however, disproving the hypothesis that time spent ruminating reduces with increased consumption at the feeder station. This conclusion is likely influenced by the precision of the available data and a dedicated analysis would be required for further confirmation and validation. Additionally, the quantity of feed being delivered by the SSF to the animals is less than 1/14 of their daily feed consumption, which would have minimal influence on the rumination of the cattle.

Due to limitations in data reliability from the MooMonitor+ collars, as a result of offline periods, variations in SSF conditions and data quality issues, it was not possible to establish a consistent trend to summarise changes in animal behaviour over the course of the experimental trial. It is generally recognised that animal behaviour appears to remain stable throughout the trial period. During the majority of the experimental trial, feed delivery at the SSF is set to approximately 0.862 kg which contributes a small proportion of animal DMI. The heifers graze most of their diet from the pastures around them, as such, the small amount of supplement supplied did not appear to alter their standard behavioural patterns.

There are clear trends in daily behaviour however, as seen in *Figure 4.13* and *Figure 4.14*, and for this reason, feed resets at the SSF can be timed to match standard behavioural patterns, maximising the efficacy of the relevant feed supplement. Exact timings will depend on the activation time and effective duration of methane mitigating supplements, however it is generally desirable to target rumination (Hegarty et al., 2021). As an example, for an

supplement which takes half an hour to activate within the rumen and has an effective operation time of six hours, daily SSF reset can be timed one to two hours prior to the end of the morning grazing period. Precision timings for feed delivery of methane mitigating supplements has not been conducted in this thesis, however would be a valuable contribution to future research. Depending on the season this could be between 09:00 and 10:00. This timing would maximise the efficacy of the feed supplement by targeting the optimum period of rumination for the herd.

4.5 ACCURACY OF MASS DELIVERY

To determine the viability of the SSF system to be able to deliver methane mitigating supplements to grassfed cattle, the accuracy of feed delivery had to be determined. Methane mitigating feeds have specific intake tolerances which must be achieved to ensure animals receive the correct dose of supplement, not only for their methane mitigating properties but also for their health (Condie et al., 1983; Villar et al., 2021).

The four individual trays used by the SSF to deliver feed each require individual calibration, resulting in variations in quantity of feed being delivered at each station. The result of this is that as animals move randomly between feed trays, the total feed they are able to consume varies. There are also two components of feed delivery which must be determined to identify programmed mass delivery at each tray, mass intervals and number of mass intervals. The mass delivery interval across the trial period is illustrated in *Figure 4.16*.

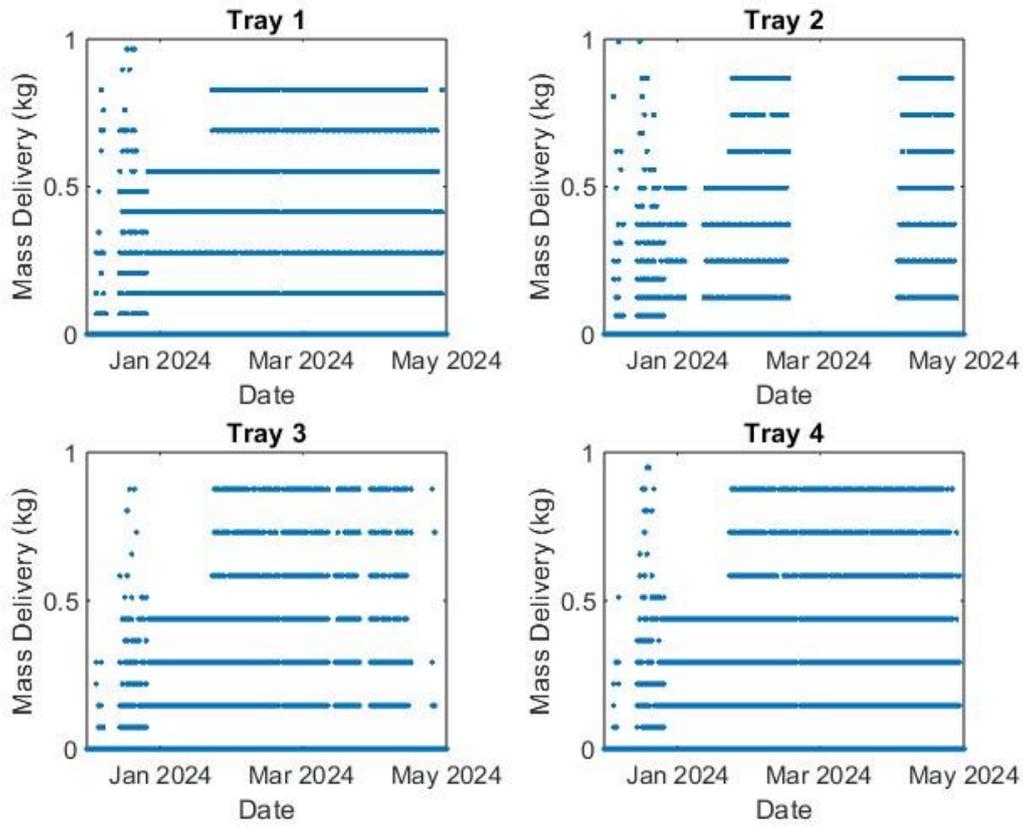


Figure 4.16: Interval mass delivery for each feeder tray during the trial period.

From this plot there are two calibration scenarios shown, before and after December 27, where calibration is modified. Tables containing feed delivery intervals for the pre- and post-recalibration scenarios are displayed in *Table 4.6* and *Table 4.7*.

Table 4.6: Pre-recalibration feed delivery intervals.

Number of Intervals	Tray 1	Tray 2	Tray 3	Tray 4
0	0.000	0.000	0.000	0.000
1	0.069	0.062	0.073	0.073
2	0.138	0.124	0.146	0.146
3	0.207	0.186	0.219	0.219
4	0.276	0.248	0.292	0.292
5	0.345	0.310	0.365	0.365
6	0.414	0.372	0.438	0.438
7	0.483	0.434	0.511	0.511
8	0.552	0.496	0.584	0.584
9	0.621	0.558	0.657	0.657
10	0.690	0.620	0.730	0.730
11	0.759	0.682	0.803	0.803
12	0.828	0.744	0.876	0.876
13	0.897	0.806		0.949
14	0.966	0.868		
15		0.992		

Table 4.7: Post-recalibration feed delivery intervals.

Number of Intervals	Tray 1	Tray 2	Tray 3	Tray 4
0	0	0	0	0
1	0.138	0.124	0.146	0.146
2	0.276	0.248	0.292	0.292
3	0.414	0.372	0.438	0.438
4	0.552	0.496	0.584	0.584
5	0.69	0.62	0.73	0.73
6	0.828	0.744	0.876	0.876
7		0.868		

Initially, the SSF was programmed to deliver 0.069, 0.062, 0.073 and 0.073 kg of supplementary feed across Trays 1 to 4. Each tray has been calibrated to deliver varying intervals of feed, making each tray's delivery unique. The maximum amount of feed delivered during this period at each tray in order is 0.966, 0.868, 0.876 and 0.949 kg, where Tray 2 exhibits two outlier events summing to 0.992 kg.

In the post-recalibration scenario, delivery mass is doubled for each interval and number of intervals is reduced, resulting in maximum mass deliveries at each tray equalling 0.828, 0.868, 0.876 and 0.876 kg. Average programmed delivery is therefore 0.8615 kg across the SSF.

The maximum variation between feed delivery at each tray in the pre-calibration scenario occurs between Trays 1 and 2, with a total difference of 0.098 kg or a 7.04% reduction from Tray 1. After re-calibration the maximum variation in feed delivery at the SSF occurs between Tray 1 and Trays 3 and 4, with a total difference of 0.048 kg, equal to a 5.48% reduction from Trays 3 and 4. The accuracy of feed delivery will be dictated by the accuracy of feeder calibration, although programmed feed delivery varies from actual feed delivery due to inconsistencies in feed density and dropped feed from the tray belt drives.

There are many occasions during the farm trial where external factors such as tray malfunctions, paddock changes and feed availability at the SSF influenced the supplement intake of the herd. To avoid skewing measures of feed delivery accuracy, a section of clean data has been cropped for the purpose of identifying actual feed delivery with programmed delivery. The cropped data was extracted between the dates of 23 January 2024 and 16 February 2024 and descriptive statistics were used to contrast the interaction accuracy during this period. Statistics are summarised in *Table 4.8*.

Table 4.8: Accuracy of feed delivery statistics between 23 January 2024 and 16 February 2024.

Date	n	Average Intake (kg)	Median Intake (kg)	Minimum Intake (kg)	Maximum Intake (kg)	Standard Deviation (kg)
23-Jan-24	60	0.872	0.854	0.808	0.948	0.045
24-Jan-24	60	0.869	0.868	0.814	0.948	0.034
25-Jan-24	60	0.854	0.876	0.146	0.934	0.116
26-Jan-24	60	0.849	0.854	0.414	0.948	0.089
27-Jan-24	60	0.837	0.868	0.146	0.948	0.126
28-Jan-24	60	0.867	0.876	0.292	0.948	0.097
29-Jan-24	58	0.848	0.868	0.146	0.938	0.115
30-Jan-24	57	0.860	0.868	0.642	0.940	0.042
31-Jan-24	60	0.874	0.876	0.814	0.940	0.037
1-Feb-24	61	0.853	0.868	0.124	0.934	0.101
2-Feb-24	60	0.873	0.872	0.816	0.946	0.038
3-Feb-24	60	0.872	0.872	0.814	0.948	0.037
4-Feb-24	60	0.865	0.868	0.678	0.940	0.049
5-Feb-24	60	0.853	0.864	0.146	0.940	0.099
6-Feb-24	60	0.851	0.852	0.146	0.940	0.100
7-Feb-24	60	0.880	0.876	0.814	0.946	0.043
8-Feb-24	59	0.853	0.860	0.138	0.938	0.102
9-Feb-24	60	0.871	0.872	0.814	0.948	0.041
10-Feb-24	59	0.874	0.876	0.814	0.940	0.036
11-Feb-24	60	0.871	0.868	0.814	0.946	0.040
12-Feb-24	60	0.872	0.868	0.814	0.948	0.043
13-Feb-24	59	0.857	0.854	0.584	0.948	0.051
14-Feb-24	60	0.859	0.868	0.138	0.948	0.102
15-Feb-24	59	0.868	0.868	0.810	0.940	0.036
16-Feb-24	58	0.874	0.868	0.816	0.948	0.038

Average:	59.6	0.863	0.867	0.540	0.944	0.066
Median:	60	0.867	0.868	0.678	0.946	0.045
Maximum:	61	0.880	0.876	0.816	0.948	0.126
Minimum:	57	0.837	0.852	0.124	0.934	0.034
Standard Deviation:	0.8	0.011	0.007	0.302	0.005	0.032

On average, 59.6 or 81.6% of animals interact daily with the SSF during this window of reliable data, consuming an average of 0.863 kg of feed. This feed allocation is within the targeted delivery range of 0.828-0.876 kg by tray calibration or ± 24 g. Maximum feed

delivery reached 0.948 kg, with an average maximum feed delivery of 0.944 kg, indicating each day at least one animal is receiving 0.068 kg more feed than the programmed maximum. With an average programmed allocation of 0.8615 kg and an actual delivered amount of 0.863 kg, the SSF achieves a delivery accuracy of 99.8% for the intended supplement quantity. Comparing programmed feed delivery with maximum feed delivery during this period, a maximum increase of 86.5 g or 9.12% is observed. The standard deviation of feed delivered by the SSF is 66 g or 7.66%.

To ensure the delivery of methane mitigating feed supplements remains within dose tolerances, supplements must be distributed within a feed allocation which can withstand a 9.12% feed delivery variation. For supplements which are being delivered purely for the purpose of methane mitigation, quantity of feed delivered should be minimised to keep costs and disruption to existing diets at a minimum. The dilution of feed will be dependent on the type of methane mitigating supplement being incorporated into the animal's diet and quantity of feed animals are being supplemented. For the animals involved in this thesis, at a live weight of 350-400 kg, DMI is 12.25 to 14 kg per day (Morton et al., 2007). Larger, adult dairy animals may reach 500-600kg and require 17.5-21 kg DMI per day. In a grazing system, most Tasmanian (location of the experiment) grasses provide all the nutrition an cow requires (Morton et al., 2007) and therefore supplementation can be kept to a minimum. *Table 4.9* depicts the percentage tolerance of each investigated methane mitigating supplement relative to itself, where tolerance is calculated assuming an average dosage is allocated.

Table 4.9: Tolerance of methane mitigating supplement delivery, adapted from (Hegarty et al., 2021). Dosages are in various units with tolerance calculated based off an average delivery dilution. For units and more information on dosage see CHAPTER 2.

Supplement	Minimum Dose	Maximum Dose	Average Dose	Percent Tolerance
3-NOP	40	340	190	57.89%
Asparagopsis	0.2	0.91	0.555	27.93%
Antibiotic rumen modifiers	16	50	33	3.03%
Nitrate	1	2	1.5	33.33%
Essential Oils	1	2	1.5	33.33%
Saponins	0.1	0.5	0.3	33.33%
Tannins	10	40	25	20.00%
Biochar	0.5	1	0.75	33.33%

Supplements with a tolerance greater than the delivery accuracy of the SSF (9.21%) are suitable to be delivered at this feeder station. With the exception of antibiotic rumen modifiers, all supplements which have been investigated can be delivered by the SSF within the boundaries identified in previous studies. Antibiotic rumen modifiers require a delivery tolerance tighter than that which can be provided by the SSF, making them poorly suited for use in Australian grazing operations.

4.6 IMPACTS OF FEEDER MALFUNCTIONS ON INTERACTION RELIABILITY.

During the study, two of the feeder trays experienced malfunctions which prevented them from delivering feed supplement to the trial herd. Tray 2 exhibited two malfunction periods, the first lasting several days, the secondary period lasted far longer. Tray 3 in comparison exhibited three breakdown periods, lasting up to one week, which occurred in the later stages of the trial. These periods ranged between the following dates:

Tray 2:

- 5 – 11 January, 6 days.
- 18 February – 3 April, 45 days.

Tray 3:

- 12 – 15 March, 3 days.
- 25 – 30 March, 5 days.
- 17 – 24 April, 7 days.

Herd responses to tray malfunctions have been investigated from the data collected at the SSF, with herd average mass intake at each of the feeder trays shown in *Figure 4.17*. Significant fluctuations in supplement intake at individual feeder trays are identified during the trial period, excluding 21 February 2024 where the system was temporarily unavailable to the animals. When peaks and negative peaks occur at each feeder tray these correlates with opposing responses at the remaining trays. This, combined with the observation that no animal consumes all of its daily intake from a single feeder tray, highlights the importance of feeding ‘options’ and redundancy in a smart feed delivery system.

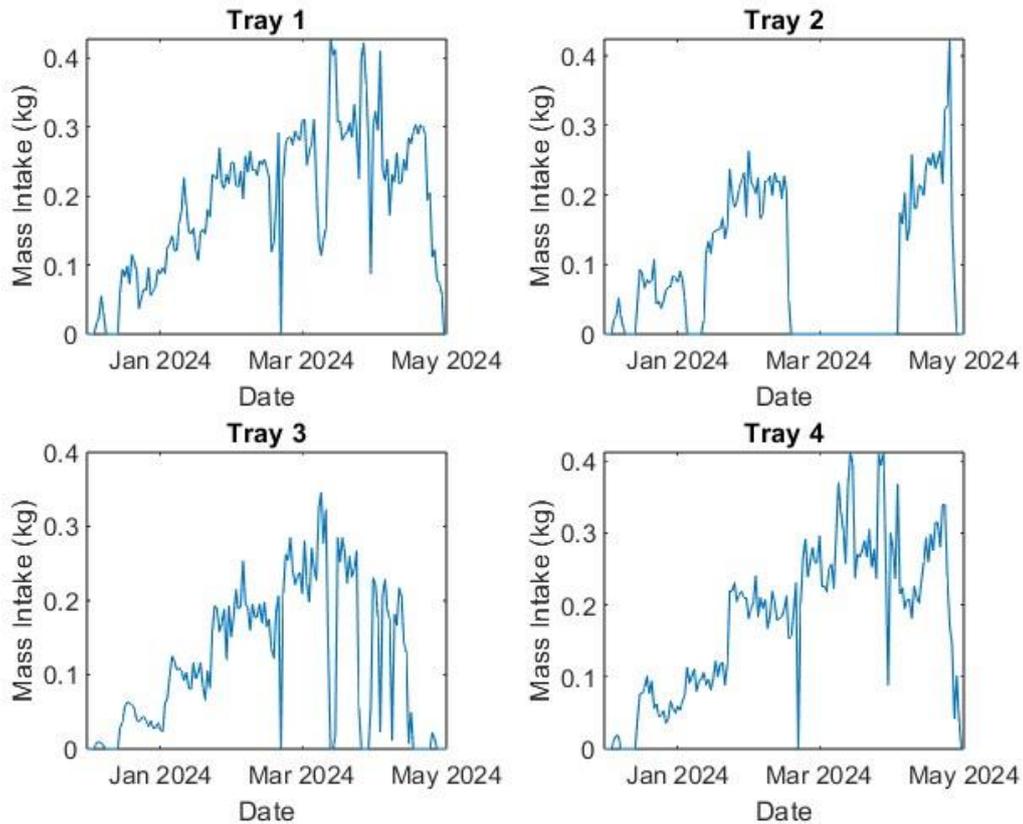


Figure 4.17: Herd averaged daily mass intake for each individual feed tray.

Cattle are grazing animals and are therefore inclined to move while feeding, this is demonstrated by their tendency to walk while grazing pasture and instigated by their need to find fresh feed (Larson-Praplan et al., 2015; Zhao & Jurdak, 2016). A feeding system which allows animals to follow their natural instincts and harnesses this behaviour, hypothetically encourages interaction, whilst nullifying the negative impact of fluctuations in feed availability at each feeder tray. The most significant malfunction event occurred at Tray 2, and lasted for 45 days. A comparison between herd feed interactions before, during and after this event has been illustrated in *Figure 4.18*, highlighting the SSF Tray 2 offline state. This figure also illustrates the range of data used to statistically investigate the major malfunction period, where all data is used after feed intake is returned to just under 1.0 kg

after the ~0.5 kg feed period. This period is filtered between 24 January - 1 May 2024 which is equivalent to 98 days worth of data, during which Tray 2 is online for 51 days.

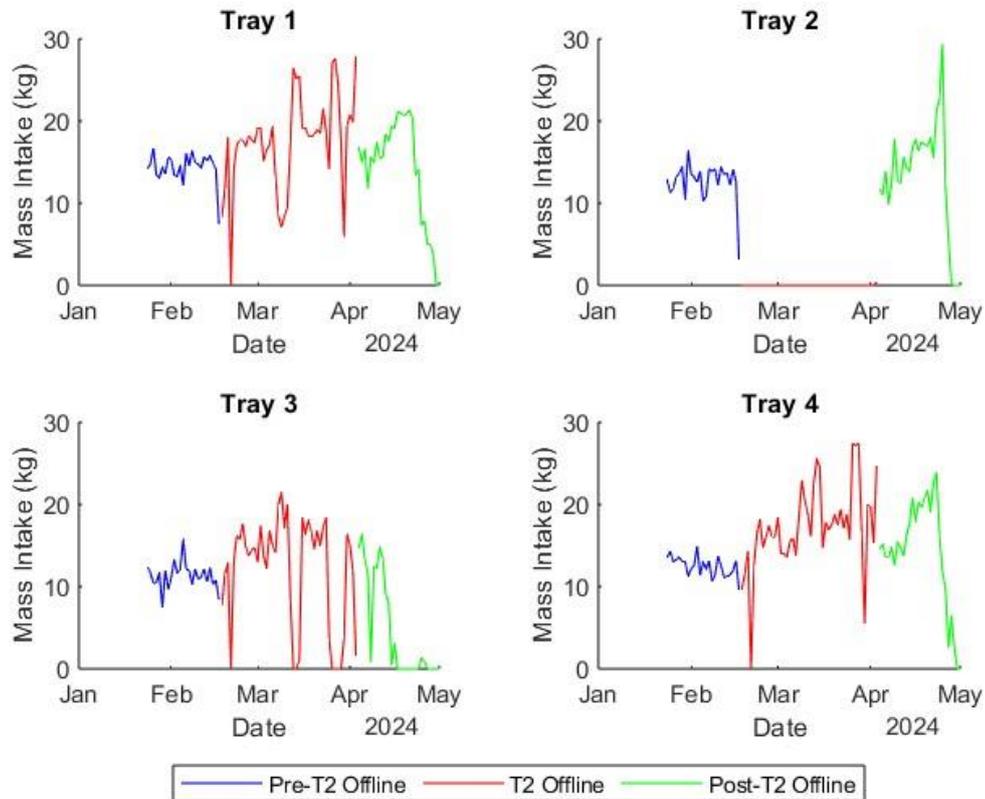


Figure 4.18: Pre-, during, and post-total herd intakes relative to Tray 2 going offline.

The feeder states illustrated in *Figure 4.18* have been processed for mean, median, standard deviation, minimum and maximum total daily herd mass intakes and summarised in *Table 4.10*. This data is divided by feeder tray into pre, during and post Tray 2 going offline conditions.

Table 4.10: Tray 2 malfunction comparison with other operational feeder trays.

Feeder Tray	Condition	Mean	Median	Standard Deviation	Minimum	Maximum
Tray 1	PreT2Offline	14.324	14.628	1.831	7.314	16.698
	T2Offline	17.331	18.078	5.877	0.000	27.876
	PostT2Offline	14.115	15.594	6.540	0.000	21.390
Tray 2	PreT2Offline	12.638	13.144	2.446	2.976	16.368
	T2Offline	0.008	0.000	0.055	0.000	0.372
	PostT2Offline	13.312	14.074	7.031	0.000	29.388
Tray 3	PreT2Offline	11.295	11.680	1.600	7.446	15.768
	T2Offline	11.883	14.527	6.782	0.000	21.462
	PostT2Offline	4.729	0.657	6.175	0.000	16.352
Tray 4	PreT2Offline	12.433	12.556	1.241	9.490	14.892
	T2Offline	17.311	17.009	5.193	0.000	27.448
	PostT2Offline	14.219	14.965	6.666	0.000	23.944

Malfunction analysis has been compared in the form of box and whisker plots delineated by malfunction scenario and tray number, as illustrated in *Figure 4.19*.

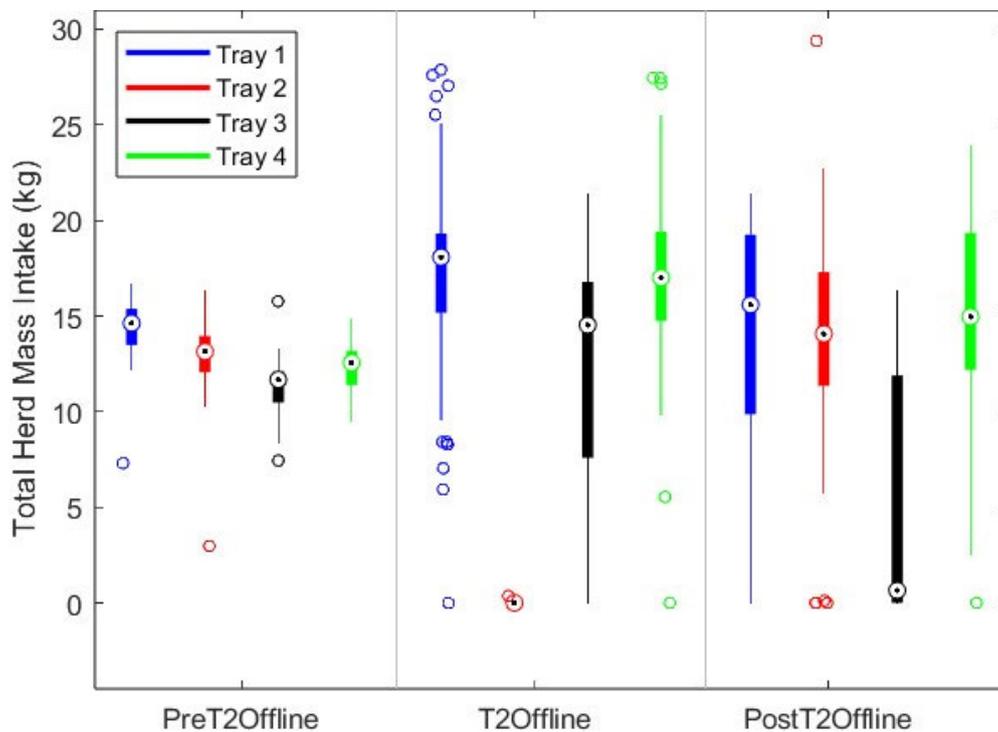


Figure 4.19: Box and whisker plot comparison of herd averaged total daily mass intakes during long-term feeding of ~0.8615 kg of feed supplement. Malfunction scenarios of pre-, during and post- Tray 2 malfunction are contrasted.

As is depicted in this figure, it was found that feed intake is most stable during the pre-malfunction scenario, with the least deviation from mean and median values identified during this time. The variations in feeding calibrations are also visible in this plot, with Tray 1 delivering 14.324 kg of feed as a herd daily average among the 73 heifers. The average total consumption of feed during this period is 12.673 kg between each of the feeder trays, with a standard deviation of 1.78 kg. Tray 3 delivers the lowest quantity of feed supplement, at 11.295 kg per day and all trays are fully operational during this time. Due to the pre-scenario being the most stable period of recorded data, it was used to compare to the during and post-malfunction scenarios.

During the 45-day period where Tray 2 experiences a system malfunction, feed delivery drops to 0. The impact on the remaining, operational trays is an immediate increase in their own delivery, although Tray 1 still delivers the most supplement. Trays 1, 2 and 4 demonstrate increases in mean feed delivery by 17.34%, 4.95% and 28.17% respectively. In contrast, when calculated by median each of these trays increases feed delivery by 19.08%, 19.59% and 26.18% respectively. During the period of Tray 2's major malfunction, Tray 3 also experienced two, short periods of malfunction resulting in 0 feed delivery. When these events occurred, Trays 1 and 4 demonstrated further increases in feed delivery, reaching maximum outputs of 27.876 kg and 27.445 kg per day respectively.

The post- Tray 2 malfunction scenario sees Tray 2 return to full functionality, however Tray 3 experiences further issues which influenced its capacity to reliably deliver feed. During this period Tray 1 exhibits a 1.48% decrease in mean feed delivery while Trays 2 and 4 demonstrate 5.08% and 12.56% increases. Tray 3 delivers an average of 4.729 kg and

median of 0.657 kg, demonstrating the varying reliability of this tray during the post-malfunction period. The median average total mass intakes increased by 6.19%, 6.61% and 16.1% respectively for Trays 1, 2 and 4 with respect to the pre-malfunction period. The combined results of the malfunction cases are shown in *Table 4.11*.

Table 4.11: General statistics for pre-, during and post-malfunction scenarios.

Scenario	Mean	Median	Standard Deviation	Minimum	Maximum
Pre-T2 Offline	12.673	13.002	1.780	6.807	15.932
T2 Offline	11.633	12.404	4.477	0.000	19.290
Post-T2 Offline	11.594	11.323	6.603	0.000	22.769

Mean and median total feed intake is reduced on average across the herd. Between the pre-malfunction and Tray 2 malfunction periods, total average herd mean, and median mass intake decreased by 8.21% and 4.6%, respectively. Mean and median intake was further decreased between the Tray 2 malfunction period and post-malfunction, reducing by an additional 0.34% and 8.71%, respectively. The reduction in total feed delivery during malfunction events highlights the importance and limitations of redundant trays within a smart feed delivery system.

It is evident from these findings that providing multiple sources of feed to animals reduces the impact of a system malfunction on animal feed consumption, implying the importance of redundancy in a computer-controlled system. This concept is supported by the feeding behaviour of grazing cattle, where cattle move around while feeding, encouraging them to interact with multiple feed bins in a broader feeding event (Larson-Praplan et al., 2015; Zhao & Jurdak, 2016).

These findings suggest that as a research tool the C-Lock SSF may be limited in its capacity to deliver four separate feed supplements to grazing animals. If a tray, or multiple trays

experience a systems malfunction, entire groups of a herd/study could be excluded from receiving their allocated feed. As such, studies comparing different feed within the same test mob should be performed with redundancy built into the experiment, with at least two trays delivering the same feed to the same group of animals. For industry application, however, having multiple feed bins grants a vital redundancy to the system which ensures that even in the event of hindered operational capacity, animals can still receive their allocated supplement.

4.7 CHALLENGES ENCOUNTERED AND LIMITATIONS OF THE STUDY

4.7.1 MooMonitor+ collar availability

In addition to malfunctions at the SSF, the MooMonitor+ collars went offline from February 17, limiting the duration of data collected by them. An example plot of the impacted data is shown in *Figure 4.20*.

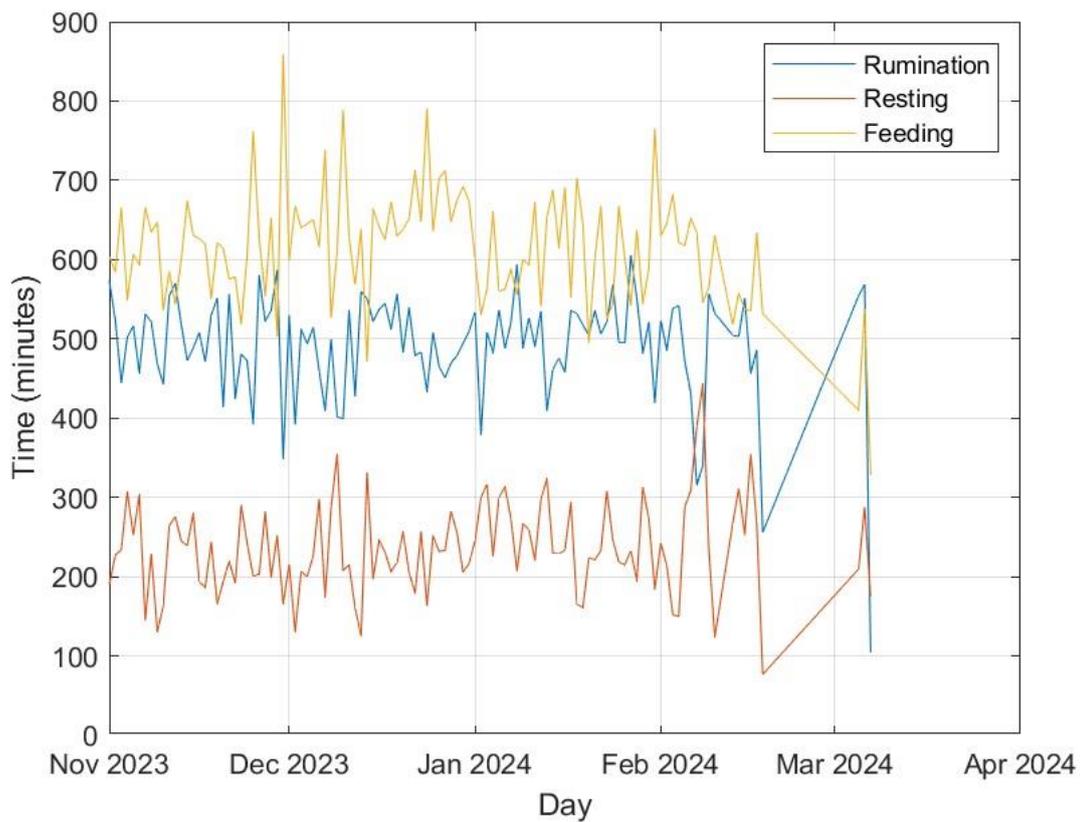


Figure 4.20: MooMonitor+ collar data collected at TDRF, data goes offline from 17 February.

Having the MooMonitor+ collars go offline prevented further comparison of animal behaviour and SSF interaction in the final months of the trial, fortunately however three and a half months of reliable interaction behaviour was collected, which provided a valuable insight into animal behavioural trends.

4.7.2 Problems identified with the SSF

During the initial stages of training the heifers (acclimatisation period) on the SSF several issues were identified regarding how the animals were interacting with the feeder, including;

1. Animals rubbing against the SSF, with potential to open or damage electronic components.
2. SSF signal range was too limited when being moved between paddocks.
3. Dominant animals would ‘bully’ others out of the feeder to acquire their food allocation.

To counter these issues and prevent them from escalating, modifications were made to the system, including;

1. Yard or temporary wire fencing was placed around the SSF, extending from the existing race system and preventing access to the panelling of the feeder.
2. An antenna was added to the SSF to boost its range.
3. Vision shields were added to the four races extending from the feeder, blocking the external view of animals to the feeding bins.

These modifications are shown in Figure 4.21, *Figure 4.22* and *Figure 4.23*, in the order they are listed above.



Figure 4.21: Yard fencing surrounding SSF.



Figure 4.22: Vision shields attached at each of the feed bins.



Figure 4.23: Booster antenna booster attached to the SSF.

4.7.3 Limitations

This study was conducted on an operational farm to assess the viability of delivering methane mitigating supplements to grazing dairy animals using an SSF. There were therefore many external variables to contend with including rotational management, feeder refills and trailer movement. This, combined with the period of tray malfunctions, has significantly influenced the data and in some cases limited the quantity of clean, reliable data available for analysis.

As a component of trial design, and apart from the month of collar data collected prior to the introduction of the SSF, there was no control group used in this study to draw comparisons with. All conclusions which have been made have been drawn from comparisons with other literature or comparisons against individual animals and the herd. This method has limitations in precision of results, as some comparisons have been drawn based on qualitative information rather than quantitative results.

Feed palatability and digestibility play major parts in dictating supplement feed uptake, especially in grazing environments. Simply, poor palatability and/or nutrition limits consumption reliability. The impact of supplement palatability was not investigated for the animals in this study. This is a knowledge gap particularly with regards to methane mitigating supplements which warrants further investigation in future studies.

Furthermore, this study did not investigate when animals expel methane relative to feeding and rumination. The conclusions to the viability and optimal timings for delivering methane mitigating supplements to grazing animals have been drawn based on the modes of action of methane mitigating supplements, as identified in CHAPTER 2 BACKGROUND AND LITERATURE REVIEW.

This thesis has specifically investigated the interaction behaviour of grazing dairy heifers. The trial was performed in a cool, temperate climate under a rotational grazing system. The results extracted from this study are specific to these conditions and are likely to vary depending on location, climate, breed and operation system. In performing further work, conclusions from this thesis can serve as a valuable baseline for research into the impacts of these variables on animal interaction and behavioural reliability around a SSF. Additional research is required to confirm the unique influence on interaction reliability of location, climate, breed and operation system.

4.8 IMPLICATIONS

The delivery of methane mitigating feed supplements to grazing dairy cattle is a viable option for graziers to reduce their carbon footprint when considering the efficacy of the SSF delivery system. The system is effective at delivering supplements to more than 80% of the herd within the dose tolerances of methane mitigating supplements, and by timing feed allocation resets, the timing of supplement delivery can be controlled. By controlling the timing of supplement delivery, the behavioural patterns of grazing animals can be targeted to maximise the effective impact of these supplements on methane mitigation within the rumen.

On top of these physical measures of efficacy there are other considerations which can limit the uptake of computer-controlled feed delivery such as the SSF within industry. Adoption factors such as costs of investment, upkeep and maintenance are key factors which concern farmers regarding the uptake of delivery methane mitigating supplements to grazing animals (Marmont et al., 2024). Ongoing costs such as management time and labor are key areas of

concern for grazing dairy operators who are generally time poor (Dela Rue et al., 2019; Santhanam-Martin et al., 2022). In Australia, the successful implementation of a computer-controlled feed delivery system such as the SSF will be dictated by supplement availability and legal licensing, ease of transport across paddocks, limited refill requirements, reliability/redundancy against malfunction and the implementation of carbon credits to counterbalance the cost of implementing these systems.

The implementation of computer-controlled feed supplement delivery systems throughout the nation should be performed through consultation with operators, to ensure solutions are practical and aligned with industry needs.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The viability of the C-Lock Inc. Super SmartFeed system for the delivery of methane mitigating supplements in grazing environments were investigated through a cohort study. From the data collected through the Super SmartFeed trailer, it was identified that at least 80% of the animals in the herd interacted daily with the system, with 68.89% of animals consuming their allocation within the first four hours of feed becoming available. The implication of this is that the herd develops a supplement consumption routine, which farmers can manipulate to maximise the efficacy of the methane mitigating supplements being delivered.

From the MooMonitor+ data collected; herd behaviour was identified to be stable throughout the trial duration. Across the period of a day, three peaks in feeding behaviour were observed at approximately 01:00, 09:00 and 20:00, where feed was primarily consumed from 20:00 to 09:00. Rumination was found to occur primarily during the middle of the day, between 10:00 and 19:00, making this period a valuable target for methane mitigation in industry applications.

The accuracy of the SSF system when delivering supplements is largely dictated by tray calibration, however factors such as feed clumping and spill losses all impact accuracy. In this trial the programmable accuracy of the SSF was within 24 g of the target allocation, while actual delivery was within ± 66 g, with a maximum deviation of 86.5 g or 9.12%. With this accuracy, the majority of methane mitigating supplements can safely be delivered to individual animals within the herd.

During the trial period several tray malfunctions occurred, where a major malfunction stopped the operation of Tray 2 for 45 days. While these malfunctions limited the quality of a large proportion of SSF data, the opportunity to assess the system in the event of a system malfunction was utilised. It was identified that during the event of a tray going offline total feed consumption at the SSF decreased by 8.21%. While a hindrance to overall efficacy, the general function of the system was maintained despite it operating at only three-quarter capacity. This redundancy grants operators time to organise a solution without completely losing the benefit of the system.

Overall, this research project has provided a greater understanding of animal behaviour around a computer-controlled supplement delivery system, in an environment which is traditionally uncontrolled and challenging to monitor. The technical application of the SSF for the delivery of methane mitigating supplements, is a viable option for grazing operators to incorporate into their existing operations, granting them the capacity to reduce the Australian agricultural industry's environmental footprint.

5.1 RECOMMENDATIONS FOR FUTURE RESEARCH

There are a wide range of opportunities for future research which have arisen from questions raised during the execution of this thesis. These have been identified from the synthesis of existing literature, the completion of design methodology, and investigations into trial results, and have been explored briefly in the following points.

- Investigating the impact of adjusting reset times and implementing multiple feed resets at the SSF on the interaction behaviour of cattle. This can be used to identify the use case of the SSF across a variety of feeding operations.

- For animals involved in a milking rotation, investigations into the impact of rotation on rumination, resting and feeding behaviour would be valuable to industry. Collars are commonly available on dairy operations, data from various farms with differing routines would be accessed and contrasted to optimise supplement delivery times. Ensure similar breed and climate conditions for comparability.
- The impact of feed palatability has not been investigated in this thesis, although controlled experiments from previous work has investigated individual supplement palatability to the point of feed refusal. This has not been done in a comparative grazing application however, where future work could compare the palatability of methane mitigating supplement against one another.
- An investigation into the needs of graziers within the Australian grazing industry could be conducted to identify how the American engineered SSF design can be optimised for Australian production systems.

CHAPTER 6. REFERENCE LIST

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APPENDIX A: PROJECT SPECIFICATION

Project Specification

For: Bradley Lawrence

Title: Evaluation of a C-Lock Super SmartFeed trailer for controlled feed supplement delivery in grassfed dairy applications.

Major: Agricultural Engineering

Supervisor: Dr Jazmine Skinner

Enrolment: ENP4111 ONC YL1, 2024

Project Aim: To analyse behavioural data collected using collars and a C-Lock Inc. Super SmartFeed (SSF) trailer, to identify the efficacy of delivering methane mitigating supplements to grazing cattle.

Programme: Version 2, September 2024

1. Conduct background and literature review of existing research into the challenges facing the agricultural industry, methane mitigating supplements, animal behaviour, monitoring methods and devices, and herd dynamics.
2. Complete an animal ethics assessment with the UniSQ animal ethics committee to receive an animal ethics exemption for the work completed at another institution.
3. Investigate the animal interaction behaviour between herd and individual animals at the SSF, as well as animal behavioural patterns around the SSF through MooMonitor+ collar data. Use prior research to focus the key research questions.
4. Utilise MATLAB to process interaction and behavioural data around the SSF system, producing key figures and statistics focussing on the objectives to:
 - a. Assess the interaction reliability of herd and individual animals around the SSF, with emphasis on animal supplement allocation intake.
 - b. Determine animal behaviour outside of interactions with the SSF to establish its impact on their daily activity budgets.
 - c. Determine the accuracy of mass delivery for the purpose of delivering methane mitigating supplements in a commercial grazing environment.
 - d. Determine the impact of a systems malfunction on interaction behaviour, with emphasis on feed intake, including the built in redundancy of the SSF.
5. Combine results and literature into a relevant discussion on the efficacy of the SSF system at delivering methane mitigating supplements to grazing animals in industrial dairy applications.
6. Make relevant conclusions on the analysis performed.

APPENDIX B: ANIMAL ETHICS EXEMPTION

Ethics ETH2024-0093 (AEC): Mr Brad Lawrence (Student) (Prior approval)

Academic/Researcher	Mr Brad Lawrence (Student) Dr Jazmine Skinner
Project	Evaluation of controlled feed supplement delivery systems in agriculture and how they may be used in grass-fed systems.
Division	Vice-Chancellor's Division Academic Division
Faculty/Department	Pro Vice-Chancellor's Office (Engagement) Academic Affairs

Ethics application

Overview

Application initiated by:

Mr Brad Lawrence

Ethical Considerations

Are you working with animals or humans?

Animals

Do you have a current approval from another Ethics Committee to conduct this project?

Yes

External host department

Tasmanian Institute of Agriculture

Project title

Evaluation of controlled feed supplement delivery systems in agriculture and how they may be used in grass-fed systems.

Project summary

In this Engineering Honours project I will assess existing data collected by the Tasmanian Institute of Agriculture on their research farm. This data has been collected from cattle using MooMonitor+ collars by Dairy Master and RFID ear tag recognition. Using this data, along with research of feed systems I will evaluate the viability of cattle feed systems to deliver controlled doses of feed supplements in grass-fed situations. This analysis will include a cost evaluation, and qualitative assessments of utility, durability and capacity for control.

Host department

[School of Agriculture and Environmental Science](#)

Project duration

1 year

Is your research being conducted within Australia?

Yes

Select all that apply:

Tasmania

Does this project relate to, and/or extend on a previously approved project.

No

Is this project funded?

No

Investigators

Principal Investigator

Dr Jazmine Skinner

UniSQ ID

██████████

Person type

Staff

Organisational area

School of Agriculture and Environmental Science

Other affiliations

Centre for Agricultural Engineering; Centre for Health Research;

Field of Research (FoR)

300301. Animal growth and development; 300303. Animal nutrition ; 310205. Proteomics and metabolomics;

Co-investigator (UniSQ Staff)

Co-investigator (UniSQ Student)

Mr Brad Lawrence (Student)

UniSQ Student ID

██████████

Type of student

Non-Academic Staff

Program

BENH - Bachelor of Engineering (Honours)

Organisational area

Sales and Student Recruitment

Field of Research (FoR)

Does the project involve co-investigators from another university or organisation?

Yes

External Investigators

Name

Richard Rawnsley

Role

Co-Investigator

Institution

Tasmanian Institute of Agriculture

Email

Richard.Rawnsley@utas.edu.au

Address

Tasmanian Institute of Agriculture (TIA), TIA - Research Institute, Cradle Coast Campus, TAS

Contact number

0428 501 972

Conflict of interest

Does the Principal Investigator have an actual, perceived, or potential personal or financial Conflict of Interest (Col) in relation to the project?

No

Do any of the Co-Investigators or External Investigators have an actual, perceived, or potential personal or financial Conflict of Interest (Col) in relation to the project?

No

Outline the Conflict of Interest (Col) and advise on how it will be managed.

Qualifications and Experience

Principal Investigator - qualifications and experience

Principal Investigator

Dr Jazmine Skinner

Qualifications relevant to project

BApp.Sc(Hons), PhD

Experience relevant to project

Lifelong experience with livestock (Family managed a 16,000acre sheep, cattle and grain property). Has worked across the supply chain; Oakey and Beef City processing facilities; 9 years experience with livestock research at the University of Queensland; during undergraduate and postgraduate study worked as a research assistant on Meat and Livestock Australia (MLA) Funded cattle and sheep research (1. Determining temperature/humidity thresholds for sheep exported from Australia to the Middle East and 2. Impact of night-time cooling on heat load in feedlot cattle); LSSH course accredited.

Co-Investigator - qualifications and experience

Co-Investigator

Richard Rawnsley

Qualifications relevant to project

Doctor of Philosophy (PhD), Agricultural Science

Experience relevant to project

229 research outputs related to the areas of crop and pasture biochemistry and physiology, crop and pasture production not elsewhere classified and agronomy under the University of Tasmania. Area Manager - Paddock Specialist at Fonterra Australia. 15 years experience working as a researcher at the Tasmanian Institute of Agriculture, roles including Dairy Centre Leader and research fellow.

Co-Investigator

Mr Brad Lawrence (Student)

Qualifications relevant to project

Final year student of a Bachelor of Engineering (Honours) majoring in Agricultural Engineering.

Experience relevant to project

Lifelong experience living and working on a Dairy farm, working with cattle similar to those used in this project. Visited and looked over the feeding set up used at the dairy research facility which is providing the data for the project.

Operational Items

Does this project include:

not applicable

The following options were available for selection:

- *Genetically Modified Organism (GMO)*
- *biological material (non-GMO), e.g. work with toxins, mutagens, teratogens, carcinogens etc.*
- *biological material native to Australia that was (or will be) collected in Queensland for commercial purposes*
- *radioactive substances and/or ionising radiation? (e.g. DXA, X-ray)*

Does this project include:

not applicable

The following options were available for selection:

- *the export, supply, publishing, or brokering of controlled goods, software, or technology*
- *an arrangement with a foreign government or foreign university that does not have institutional autonomy not applicable*
- *not applicable*

[Research and evaluation of an Australian feed supplement delivery system for grass-fed animals.](#)

First copy:

UniSQ OneDrive

Second Copy:

Institute/Centre/Faculty/School MS Team

Third copy:

Secure local desktop

How will you protect your data from loss and unauthorised access?

Data shall be password protected

Who needs access to your data?

supervisory team, research team

What is the required retention period for your data?

7 year

At the completion of the project, where will you keep your research data in order to meet the required retention period

OneDrive and hard drive

Additional Information

Do you have a UniSQ Risk Management Plan relating to the activities being undertaken in this project?

Yes

RMP Reference number

4210

UniSQ RMP Project Title

Evaluation of controlled feed supplement delivery systems in agriculture and how they may be used in grass-fed systems.

Status of approval

Current

Date of Approval

15 Mar 2024

Upload a copy of the RMP**Ethical considerations - Animal****In what way does your project incorporate animals?**

no interference with animals

no abnormal disruption of habitat

Outline of project**Using plain language provide a description of what will be undertaken**

As part of a dairy methane emissions project being conducted with Fonterra and the Tasmanian Institute of Agricultural Research, dairy cows are being fed pelleted rations via the use of a smart feed trailer. The feed trailer currently being used is a C-Lock SuperSmart Feeder and the purpose of this research project is to investigate the effect of methane reducing supplements such as Asparagopsis on dairy cattle.

This specific project seeks to analyse the behavioural data (e.g., time spent feeding, ruminating, walking, resting etc.) that has already been collected via the use of collars and RFID ear tags from 80 two-year old dairy cows that have been interacting with this smart feed trailer as part of this larger study. This data will be analysed and used alongside the research of feeding systems and types by Bachelor of Engineering student Brad Lawrence as part of his final year honours project, to support and evaluate the viability of controlled feed supplement delivery systems for grass-fed operations.

This project therefore seeks an ethics exemption for the analysis of behavioral data only, that has already been collected as part of the above aforementioned study.

Attached files

RMP.docx

NUMBER	RISK DESCRIPTION	TREND	CURRENT	RESIDUAL
4210	Evaluation of controlled feed supplement delivery systems in agriculture and how they may be used in grass-fed systems.		Low	Low
DOCUMENTS REFERENCED				
RISK OWNER	RISK IDENTIFIED ON	LAST REVIEWED ON	NEXT SCHEDULED REVIEW	
Brad Lawrence	11/03/2024	15/03/2024	15/03/2025	
RISK FACTOR(S)	EXISTING CONTROL(S)	PROPOSED CONTROL(S)	OWNER	DUE DATE
Hazard: Working with electronic equipment. Laptops, Desktops, Hard-drives. Risk: Electrical Shock	Control: Use items for their intended purposes.	No Control:		
Hazard: Long periods at workstation, excessive screen time. Risk: Fatigue as a result of sustained static posture.	Control: Taking breaks, changing between sitting and standing desk arrangements.	No Control:		
Hazard: Corrupted data files. Risk: Loss of work.	Control: Three copies of data will be stored in accordance with the data management plan.	No Control:		
Work with animals is performed externally by profession researchers and farmers as part of the Tasmanian Institute of Agricultures Diary Research Facility.	Control: NA	No Control:		

APPENDIX C: DATA MANAGEMENT PLAN



View data management plan

[Show changes](#)

Research Data Management Plan (RDMP)

Plan title

Research and evaluation of an Australian feed supplement delivery system for grass-fed animals.

Description

The data in this project is animal behavioural data relating to animal interactions with a feeder system. This is measured using industry available collars and RFID identification through NLIS tags.

Language

English

Data Collection

How will the data be collected or created?

How are you planning to collect your data?

Data not being collected in this project. Data is being provided by collaborator.

How will you name and structure your folders and files?

Dates

Outline how you will manage your file versioning

Underscore number

Outline how you will use metadata to describe your data

Individual animals are assigned numbers.

Add new dataset

Title

TBC

Description of the dataset

Behavioural Data: feed consumption, visitation, movement patterns

Type of dataset

Spreadsheet

What is the format of the data?

Electronic

How does your chosen format and software enable sharing and long-term access to the data?

Universal format, can be easily forwarded and saved in multiple places.

Expected size of dataset

0GB - 4GB

Keywords to describe the dataset

SECTIONS

[Research Data Management Plan \(RDMP\)](#)[Data Collection](#)[Ethics and Legal Compliance](#)[Storage and Data Protection](#)[Selection and Preservation](#)[Data Sharing](#)[Responsibilities and Resources](#)

VERSIONS

14 Mar 2024 (Brad Lawrence (Student))[14 Mar 2024 \(Brad Lawrence \(Student\)\)](#)[14 Mar 2024 \(Brad Lawrence \(Student\)\)](#)[14 Mar 2024 \(Brad Lawrence \(Student\)\)](#)

Time
Animal Tag
Feed Type
Feed allocation
Daily Consumption
Age
Resting Patterns
Grazing Patterns
Movement Patterns
Does this dataset contain personal information?
No
Does this dataset contain sensitive data?
No

Ethics and Legal Compliance

Are you aware of any ethical issues related to the data this RDMP describes?

Yes

Please complete an ethics application and link to it here

<https://researchadmin.usq.edu.au/z4vy5/ethics-application-eth2024-0093->

Does any of the following apply to your data?

Some or all of my data is subject to ethics approval

If other, please specify

How will you manage any ethical issues?

Have you considered obtaining consent for data preservation and sharing?

Yes

Have you obtained consent?

Yes

Will the data be identifiable?

Re-identifiable (identifiers have been removed)

How will you protect the identity of participants if required?

Any identifiable information will be removed where applicable.

Is this data of a sensitive nature?

No

How will sensitive data be handled to ensure it is stored and transferred securely?

Does this data relate to First Nations Peoples?

No

How will you manage copyright and Intellectual Property Rights (IP/IPR) issues?

Who owns the data?

Joint Ownership

Please specify parties

Tasmanian Institute of Agriculture.

Will the data be protected by Australian Copyright?

No

Will the data be created or collected outside Australia where equivalent copyright applies?

No

If so, where?

How will the data be licensed for reuse?

NA

Are you using existing or third party datasets for this project?

Yes

Please provide details

Provided by the Tasmanian Institute of Agriculture. This project is a collaboration, TIA provides the data, as part of their research Brad Lawrence will process and analyse the data.

Are there any restrictions on the reuse of third-party data?

No

If yes, please explain

Storage and Data Protection

How will the data be stored and backed up during the research?

How much storage do you require?

Less than 5TB

Will you need to include charges for additional services?

No

If yes, please provide details

Do you require storage for non-digital data?

No

If yes, please provide details

Specify where you will store 3 copies of your data.

For more details about UniSQ research data storage options, refer to [UniSQ's Research Data Bank](#) (ReDBank)

First copy

UniSQ OneDrive

Second copy

Institute/Centre/Faculty/School MS Teams

Third copy

Secure local desktop

How will you manage access and security?

How will you protect your data from loss and unauthorised access?

Data shall be password protected

Who needs to access your data?

supervisory team, research team

APPENDIX D: RISK MANAGEMENT PLAN

Name	Evaluation of controlled feed supplement delivery systems in agriculture and how they may be used in grass-fed systems.	Current Rating	Residual Rating
		Low	Low
Location	Toowoomba		
Business Unit		Last Review Date	Risk Owner
School of Engineering		15/03/2024	Brad Lawrence
Risk Assessment Team		Risk Approver	
Jazmine Skinner (U8015173@usq.edu.au, Lecturer (Animal Science), +61 7 4631 2226)		Jazmine Skinner	
Brad Lawrence (U1147855@usq.edu.au)			
Additional Notes			
Describe task / use			
<p>In this project cattle feed delivery systems will be analysed to the goal of a cost effective, robust and accurate feed delivery system which can be used to accurately deliver feed supplements in a grass-fed environment. Additionally, this shall be supported by animal behavioural and interaction data provided by the Tasmanian Institute of Agriculture. The aim of this project is to identify the viability and potential design considerations required to design a feeder system which is useful and cost effective in the agricultural sector.</p>			

Risk Factors

Risk Factor

Electrical

Description

Hazard: Working with electronic equipment. Laptops, Desktops, Hard-drives.
Risk: Electrical Shock

- Does the work involve:
 - Low Voltage Electricity -- Yes
- Could hazards be caused by:
 - Incorrect installation? -- Yes
 - Will the work be affected by the loss of power? -- No
 - Will electricity be used in wet or potentially wet conditions? -- No

Very Low	Very Low		
Existing Controls	Proposed Controls		
<ul style="list-style-type: none"> 5 - Administration: Use items for their intended purposes. 	Description	Responsibility	Target Date
	No Control:		

Risk Factor	Ergonomics and Manual Handling
Description	
<p>Hazard: Long periods at workstation, excessive screen time. Risk: Fatigue as a result of sustained static posture.</p>	<ul style="list-style-type: none">• Does the activity involve manual tasks: -- No• Does the work involve:• Does the work involve sustaining static postures for long periods of time e.g. sitting or standing? -- Yes• Are there ergonomic hazards related to:• Work station or work area design? -- Yes

Very Low	Very Low		
Existing Controls	Proposed Controls		
<ul style="list-style-type: none"> 1 - Elimination: Taking breaks, changing between sitting and standing desk arrangements. 	Description	Responsibility	Target Date
	No Control:		

Risk Factor	Other
Description	
Hazard: Corrupted data files. Risk: Loss of work.	<ul style="list-style-type: none">• -- --

Very Low	Very Low		
Existing Controls	Proposed Controls		
<ul style="list-style-type: none"> 5 - Administration: Three copies of data will be stored in accordance with the data management plan. 	Description	Responsibility	Target Date
	No Control:		

Risk Factor	Animals
Description	
<p>Work with animals is performed externally by profession researchers and farmers as part of the Tasmanian Institute of Agricultures Diary Research Facility.</p>	<ul style="list-style-type: none">• Does the work involve::• Animals - Large (e.g. horses/cattle) -- Yes• Is there potential for:

Low	Low		
Existing Controls	Proposed Controls		
<ul style="list-style-type: none"> No existing controls required: NA 	Description	Responsibility	Target Date
	No Control:		

Appendix

Risk Matrix Level

Very Low	Task can proceed upon approval of the risk assessment by the relevant supervisor, manager or higher delegate
Low	Task can proceed upon approval of the risk assessment by the relevant supervisor, manager or higher delegate
Medium	Task can proceed upon approval of the risk assessment by a Category 4 or higher delegate
High	Task can only proceed in extraordinary circumstances provided there is authorisation by the Vice Chancellor
Extreme	Task must not proceed. Appropriate and prompt action must be taken to reduce the risk to as low as reasonable practicable

If creating or collecting data in the field, how will you ensure its safe transfer into your main secured systems?

Data will be accessed via Microsoft teams

Selection and Preservation

What is the required retention period for your data?

7 year

At the completion of the project, where will you keep your research data in order to meet the required retention period?

OneDrive and hard drive

Data Sharing

Is your data able to be shared?

Yes

Why not?

If the data can be listed in Research Data Australia to facilitate reuse and sharing, what level of access to the data will be possible?

Unknown at this stage

Will you share data via a repository, handle requests directly or use another mechanism?

Handle requests directly.

Are there ethical issues or other restrictions in sharing your data?

No

How will this be addressed in line with the relevant ethics requirements?

Responsibilities and Resources

Who will be responsible for data management?

Who is responsible for implementing the RDMP, and ensuring it is reviewed and revised?

Jazmine Skinner

How will data management responsibilities be split in collaborative research projects?

Evenly split for parties involved.

What resources will you require to deliver your plan?

Do you require training for using any of the hardware or software identified in your data management plan?

No

If yes, please provide details

Do you require hardware or software which is additional or exceptional to existing institutional provision?

No

If yes, please specify

APPENDIX E: MATLAB CODE

```
function Data = EquipLocation(filename, dataLines)
%IMPORTFILE Import data from a text file
% DATA = EQUIPLOCATION(FILENAME)
% reads data from text file FILENAME for the default selection.
% Returns the data as a table.
%
% DATA = EQUIPLOCATION(FILE, DATALINES)
% reads data for the specified row interval(s) of text file
% FILENAME. Specify DATALINES as a positive scalar integer or a N-by-2
% array of positive scalar integers for dis-contiguous row intervals.
%
% Example:
% DATA = EQUIPLOCATION("Feeder_Data\GPS_Tracker\Equipment Tracking (ELT012)-data-May 07 2024 11_39_33.csv", [2, Inf]);
%
% See also READTABLE.
%
% Auto-generated by MATLAB on 23-Sep-2024 08:24:34

%% Input handling

% If dataLines is not specified, define defaults
if nargin < 2
    dataLines = [2, Inf];
end

%% Set up the Import Options and import the data
opts = delimitedTextImportOptions("NumVariables", 3, "Encoding", "UTF-8");

% Specify range and delimiter
opts.DataLines = dataLines;
opts.Delimiter = ",";

% Specify column names and types
opts.VariableNames = ["Time", "Latitude", "Longitude"];
opts.VariableTypes = ["string", "double", "double"];

% Specify file level properties
opts.ExtraColumnsRule = "ignore";
opts.EmptyLineRule = "read";
opts.ConsecutiveDelimitersRule = "join";

% Specify variable properties
opts = setvaropts(opts, "Time", "WhitespaceRule", "preserve");
opts = setvaropts(opts, "Time", "EmptyFieldRule", "auto");

% Import the data
Data = readtable(filename, opts);
```

end

```
function Data = IntakeMassData(filename, dataLines)
%IMPORTFILE Import data from a text file
% DATA = INTAKEMASSDATA(FILENAME) reads
% data from text file FILENAME for the default selection. Returns the
% data as a table.
%
% DATA = INTAKEMASSDATA(FILE, DATALINES)
% reads data for the specified row interval(s) of text file FILENAME.
% Specify DATALINES as a positive scalar integer or a N-by-2 array of
% positive scalar integers for dis-contiguous row intervals.
%
% Example:
% Data = IntakeMassData("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-
01_to_2024-05-02 - tray - visits.csv", [2, Inf]);
%
% See also READTABLE.
%
% Auto-generated by MATLAB on 20-Sep-2024 10:38:50

%% Input handling

% If dataLines is not specified, define defaults
if nargin < 2
    dataLines = [2, Inf];
end

%% Set up the Import Options and import the data
opts = delimitedTextImportOptions("NumVariables", 5);

% Specify range and delimiter
opts.DataLines = dataLines;
opts.Delimiter = ",";

% Specify column names and types
opts.VariableNames = ["FeederTray", "AnimalName", "AnimalTag", "Date", "IntakeKg"];
opts.VariableTypes = ["string", "double", "double", "string", "double"];

% Specify file level properties
opts.ExtraColumnsRule = "ignore";
opts.EmptyLineRule = "read";

% Specify variable properties
opts = setvaropts(opts, ["FeederTray", "Date"], "WhitespaceRule", "preserve");
opts = setvaropts(opts, ["FeederTray", "Date"], "EmptyFieldRule", "auto");

% Import the data
Data = readtable(filename, opts);

end
```



```
function Data = MooMonitorData(workbookFile, sheetName, dataLines)
%IMPORTFILE Import data from a spreadsheet
% DATA = MOOMONITORDATA(FILE) reads
% data from the first worksheet in the Microsoft Excel spreadsheet file
% named FILE. Returns the data as a table.
%
% DATA = MOOMONITORDATA(FILE, SHEET)
% reads from the specified worksheet.
%
% DATA = MOOMONITORDATA(FILE, SHEET,
% DATALINES) reads from the specified worksheet for the specified row
% interval(s). Specify DATALINES as a positive scalar integer or a
% N-by-2 array of positive scalar integers for dis-contiguous row
% intervals.
%
% Example:
% Data = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF -
2023_11_01-2023_12_31 - Org.xlsx", "Sheet1", [2, Inf]);
%
% See also READTABLE.
%
% Auto-generated by MATLAB on 20-Sep-2024 10:50:08

%% Input handling

% If no sheet is specified, read first sheet
if nargin == 1 || isempty(sheetName)
    sheetName = 1;
end

% If row start and end points are not specified, define defaults
if nargin <= 2
    dataLines = [2, Inf];
end

%% Set up the Import Options and import the data
opts = spreadsheetImportOptions("NumVariables", 100);

% Specify sheet and range
opts.Sheet = sheetName;
opts.DataRange = dataLines(1, :);

% Specify column names and types
opts.VariableNames = ["CowId", "Date", "Behaviour", "Daily_Total", strcat("Time",
string(5:100))];
opts.VariableTypes = ["double", "string", "string", "double", repmat("double", 1,
96)];

% Import the data
```

```
Data = readtable(workbookFile, opts, "UseExcel", false);

for idx = 2:size(dataLines, 1)
    opts.DataRange = dataLines(idx, :);
    tb = readtable(workbookFile, opts, "UseExcel", false);
    Data = [Data; tb]; %#ok<AGROW>
end

end
```

```
function Data = RFIDData(filename, dataLines)
%IMPORTFILE Import data from a text file
% DATA = RFIDDATA(FILENAME) reads data from text
% file FILENAME for the default selection. Returns the data as a table.
%
% DATA = RFIDDATA(FILE, DATALINES) reads data for
% the specified row interval(s) of text file FILENAME. Specify
% DATALINES as a positive scalar integer or a N-by-2 array of positive
% scalar integers for dis-contiguous row intervals.
%
% Example:
% DATA = RFIDDATA("Feeder_Data\SmartFeed_Data\CSV\rfids - 2023-12-01_2023-12-31.
csv", [2, Inf]);
%
% See also READTABLE.
%
% Auto-generated by MATLAB on 20-Sep-2024 10:34:16

%% Input handling

% If dataLines is not specified, define defaults
if nargin < 2
    dataLines = [2, Inf];
end

%% Set up the Import Options and import the data
opts = delimitedTextImportOptions("NumVariables", 4);

% Specify range and delimiter
opts.DataLines = dataLines;
opts.Delimiter = ",";

% Specify column names and types
opts.VariableNames = ["ScanTime", "CowTag", "InOrOut", "TrayIfApplicable"];
opts.VariableTypes = ["string", "double", "string", "double"];

% Specify file level properties
opts.ExtraColumnsRule = "ignore";
opts.EmptyLineRule = "read";

% Import the data
Data = readtable(filename, opts);

end
```

```
function Data = SSFData2(filename, dataLines)
%IMPORTFILE Import data from a text file
% DATA = SSFDATA2(FILENAME) reads
% data from text file FILENAME for the default selection. Returns the
% data as a table.
%
% DATA = SSFDATA2(FILE, DATALINES)
% reads data for the specified row interval(s) of text file FILENAME.
% Specify DATALINES as a positive scalar integer or a N-by-2 array of
% positive scalar integers for dis-contiguous row intervals.
%
% Example:
% Data = SSFData2("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-05-
02 - tray - visits - 2.csv", [2, Inf]);
%
% See also READTABLE.
%
% Auto-generated by MATLAB on 20-Sep-2024 10:21:03

%% Input handling

% If dataLines is not specified, define defaults
if nargin < 2
    dataLines = [2, Inf];
end

%% Set up the Import Options and import the data
opts = delimitedTextImportOptions("NumVariables", 11);

% Specify range and delimiter
opts.DataLines = dataLines;
opts.Delimiter = ",";

% Specify column names and types
opts.VariableNames = ["AnimalTag", "Feeder", "StartTime", "EndTime", "DurationSec",
"StartMassKg", "EndMassKg", "MassDiffKg", "Tray", "FeedType", "Flags"];
opts.VariableTypes = ["double", "double", "string", "string", "double", "double",
"double", "double", "double", "double", "string"];

% Specify file level properties
opts.ExtraColumnsRule = "ignore";
opts.EmptyLineRule = "read";

% Specify variable properties
opts = setvaropts(opts, "Flags", "WhitespaceRule", "preserve");
opts = setvaropts(opts, "Flags", "EmptyFieldRule", "auto");
opts = setvaropts(opts, "AnimalTag", "TrimNonNumeric", true);
opts = setvaropts(opts, "AnimalTag", "ThousandsSeparator", ",");
```

```
% Import the data  
Data = readtable(filename, opts);  
  
end
```

```
%% Animal_Mass_Intake_Herd_Individual
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To plot individual and herd averaged mass intakes over the
% course of the trial period.
%
% Prepared by Bradley Lawrence, September 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Animal Mass Intake, Herd and Individual</strong>\n')

%% Import Intake Mass Data
% Import the data using the function created using the import wizard
Data = IntakeMassData("Feeder_Data\SmartFeed_Data\CSV\" + ...
    "IntakeMass_2023-12-01_to_2024-05-02 - tray - visits.csv", [2, inf]);

% Remove AnimalTag column
Data = removevars(Data, "AnimalTag");

%% Preparation of data for processing.
% Modify data into the desired format
% Extract the tray number from the FeederTray column and convert the
% extracted string to a numeric value
Data.FeederTray = str2double(extractAfter(Data.FeederTray, "-"));
% Convert date string to date format
Data.Date = datetime(Data.Date, 'InputFormat', 'dd/MM/yyyy');

% Reorder data into date time chronological order.
Data = sortrows(Data, "Date");

% Identify animal IDs, remove all non identifiable inputs
AnimalIds = unique(Data.AnimalName);
AnimalIds = rmmissing(AnimalIds);

% Ensure plot saving directory exists, if not create the correct directory
if ~exist('Figures/Individual_Animal_Feed_Intakes', 'dir')
    mkdir('Figures/Individual_Animal_Feed_Intakes');
end

%% Plot individual animals
% Filter the data for Animal ID i
for i = 1:length(AnimalIds)

    % Extract data for the animal of interest
    animal_i = AnimalIds(i);
```

```
AnimaliData = Data(Data.AnimalName == animali, :);

% Extract all dates available
dates = unique(AnimaliData.Date);

% Pre-allocate DailyIntake
DailyIntakei = zeros(size(dates));

% Sum daily data (it is otherwise divided among different feed trays)
for j = 1:length(dates)
    DailyIntakei(j) = sum(AnimaliData.IntakeKg(AnimaliData.Date == ...
        dates(j)));
end

% Plot intake mass against date for entire time period
fig = figure('visible', 'off'); % Because so many figures are being
% produced I only want to review them later
plot(dates, DailyIntakei, '-');
ylim([0,1]); % ensure all y scales are uniform
xlabel('Date');
ylabel('Intake Mass (Kg)');
% title(['Intake Mass Over Time for Animal ', num2str(animali)]);
grid on;

% Save figures to be reviewed as a group
filename = fullfile('Figures/Individual_Animal_Feed_Intakes', ...
    sprintf('Intake_Mass_Animal_%d.jpeg', animali));
saveas(fig, filename, 'jpeg');
close(fig)

% Track where the script is up to
fprintf('Cow %d of %d complete\n', i, length(AnimalIds))

end

%% Plot Average Herd Results
% Aggregate data for the whole herd
[DatesHerd, ~, DateId] = unique(Data.Date);

% Pre-allocate array
TotalDailyIntake = zeros(size(DatesHerd));

% Sum daily data (it is otherwise divided among different feed trays)
for i = 1:length(DatesHerd)
    TotalDailyIntake(i) = sum(Data.IntakeKg(DateId == i));
end

% Compute average daily intake
AvgDailyIntake = (TotalDailyIntake./length(AnimalIds));
```

```
% Plot average intake mass against date for the herd
figure(1);
plot(DatesHerd, AvgDailyIntake, '-');
ylim([0,1]); % ensure all y scales are uniform
xlabel('Date');
ylabel('Average Intake Mass (Kg)');
%title('Average Daily Intake Mass for the Herd');
grid on;

% Save figure to file explorer
filename = fullfile('Figures',sprintf('Average_Intake_Mass.jpeg'));
saveas(figure(1), filename, 'jpeg');

%% Conclude Script
disp('- Script Complete -')
```

```
%% Herd_Averaged_MooMonitor_Plotting
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To plot average herd daily total rumination, resting and
% feeding behaviour.
%
% Prepared by Bradley Lawrence, July 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Herd Averaged Moomonitor Plotting</strong>\n')

%% MooMonitor Collar Data imported using the import wizard's generated
% function
% Import the data from all three files
File1 = MooMonitorData("Feeder_Data\MooMonitor_Data\" + ...
    "MooMonitor Raw Data TDRF - 2023_11_01-2023_12_31 - Org.xlsx", ...
    "Sheet1", [2, Inf]);
File2 = MooMonitorData("Feeder_Data\MooMonitor_Data\" + ...
    "MooMonitor Raw Data TDRF - 2024_01_01-2024_02_29 - Org.xlsx", ...
    "Sheet1", [2, Inf]);
File3 = MooMonitorData("Feeder_Data\MooMonitor_Data\" + ...
    "MooMonitor Raw Data TDRF - 2024_03_01-2024_04_30 - Org.xlsx", ...
    "Sheet1", [2, Inf]);

% Remove the first row of data from the data set. This row is a title row.
File1(1, :) = []; File2(1, :) = []; File3(1, :) = [];

% Combine all data
Data = [File1; File2; File3];

% Convert date string to date format
Data.Date = datetime(Data.Date, 'InputFormat', 'dd-MMM-yyyy');

%% Check if the number of rows is a multiple of three
if mod(height(Data), 3) ~= 0
    error('Number of rows in raw data file is not a multiple of three');
end

%% Herd Averaged Behavioural Data
% Initialise arrays to hold daily totals for each behaviour
DailyRumination = [];
DailyResting = [];
DailyFeeding = [];

% Extract unique dates and cut off after the 4th of Feb 2024, after this
```

```
% time the collars go offline and report errors.
UniqueDates = unique(Data.Date);
cutoffdate = datetime(2024, 2, 4);
UniqueDates = UniqueDates(UniqueDates <= cutoffdate);

% Loop through each unique date to compute daily averages
for i = 1:length(UniqueDates)

    % Get the data for the current date
    DateData = Data(Data.Date == UniqueDates(i), :);

    % Get unique CowIds for the current date
    UniqueCowIds = unique(DateData.CowId);

    % Initialise arrays to hold daily totals for the current date
    DailyRuminationTotals = [];
    DailyRestingTotals = [];
    DailyFeedingTotals = [];

    % Process each cow for the relevant date
    for j = 1:length(UniqueCowIds)
        cowId = UniqueCowIds(j);
        CowData = DateData(DateData.CowId == cowId, :);

        % Determine number of rows and sequence for each behaviour
        Rows = height(CowData);
        Sequence1 = 1:3:Rows;
        Sequence2 = 2:3:Rows;
        Sequence3 = 3:3:Rows;

        % Extract daily totals for each behaviour
        if ~isempty(Sequence1)
            DailyRuminationTotals = [DailyRuminationTotals; CowData.Daily_Total \
(Sequence1)];
        end
        if ~isempty(Sequence2)
            DailyRestingTotals = [DailyRestingTotals; CowData.Daily_Total \
(Sequence2)];
        end
        if ~isempty(Sequence3)
            DailyFeedingTotals = [DailyFeedingTotals; CowData.Daily_Total \
(Sequence3)];
        end
    end

    % Compute daily averages for each behaviour
    AvgRumination = mean(DailyRuminationTotals, 1);
    AvgResting = mean(DailyRestingTotals, 1);
    AvgFeeding = mean(DailyFeedingTotals, 1);
end
```

```
% Append to overall arrays
DailyRumination = [DailyRumination; AvgRumination];
DailyResting = [DailyResting; AvgResting];
DailyFeeding = [DailyFeeding; AvgFeeding];
end

% Plot the herd-averaged results
fig = figure;
plot(UniqueDates, DailyRumination, UniqueDates, DailyResting, UniqueDates, \
DailyFeeding)
xlabel('Date'); ylabel('Time (minutes)');
title('Herd Average Behavioural Movements');
legend('Rumination', 'Resting', 'Feeding')
grid on;

% Save figure to file explorer
filename = fullfile('Figures', sprintf('Herd_Average_Behavioural_Movements.jpeg'));
saveas(fig, filename, 'jpeg');

%% Conclude Script
disp('- Script Complete -')
```

```
%% Cropped Delivery Accuracy
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To crop a clean region of data to be used to calculate the
% actual delivery accuracy of the SSF.
%
% Prepared by Bradley Lawrence, September 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('Cropped Delivery Accuracy\n')

%% Import Intake Mass Data
Data = IntakeMassData("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-
05-02 - tray - visits.csv", [2, inf]);

%% Identify quality of data
MissingData = sum(isnan(Data.AnimalName)); % Count missing animal names
Missing = (MissingData ./ height(Data)) * 100; % Calculate percentage missing
fprintf('%.2g percent of mass intake data is missing\n', Missing)

%% Remove missing data
Data = rmmissing(Data); % Remove rows with missing data

%% Identify animal IDs, remove all non-identifiable inputs
% Remove animals with extreme data (IDs provided by another script)
Remove = [2212, 2216, 2218, 2245, 2257, 2258, 2263, 2270, 2272, 2274, 2277];
Data = Data(~ismember(Data.AnimalName, Remove), :);
AnimalIds = unique(Data.AnimalName);
AnimalIds = rmmissing(AnimalIds);

%% Modify data into the desired format
% Extract tray number from FeederTray column and convert to numeric value
Data.FeederTray = str2double(extractAfter(Data.FeederTray, "-"));

% Convert Date string to datetime format
Data.Date = datetime(Data.Date, 'InputFormat', 'dd/MM/yyyy');

%% Crop data from Jan 23rd
Data = Data(Data.Date >= datetime('23/01/2024'), :);
Data = Data(Data.Date <= datetime('16/02/2024'), :);

%% Aggregate data for the whole herd
% Find unique dates and calculate total daily intake per herd
[DatesHerd, ~, DateId] = unique(Data.Date);
TotalDailyIntake = zeros(size(DatesHerd)); % Preallocate array
```

```
% Loop through and sum intake data for each unique date
for i = 1:length(DatesHerd)
    TotalDailyIntake(i) = sum(Data.IntakeKg(DateId == i)); % Sum intake for each
date
end

% Compute average daily intake across animals
AvgDailyIntake = TotalDailyIntake ./ length(AnimalIds);

%% Plot average intake mass against date for the herd
figure(1);
plot(DatesHerd, AvgDailyIntake, '-*b', 'LineWidth', 1.5);
hold on;
line([DatesHerd(1), DatesHerd(end)], [0.876, 0.876], 'Color', 'k', 'LineStyle', '--',
'LineWidth', 1.2);
line([DatesHerd(1), DatesHerd(end)], [0.828, 0.828], 'Color', 'k', 'LineStyle', '--',
'LineWidth', 1.2);
ylim([0, 1]);
xlabel('Date'); ylabel('Average Intake Mass (Kg)');
% title('Average Daily Intake Mass for the Herd');
legend('Average Daily Intake', 'Maximum Mass Delivery: 0.876 kg', 'Minimum Mass
Delivery: 0.828 kg', 'Location', 'best');
grid on;
hold off;

%% Display average feed intake across the herd during this period
fprintf('Average herd intake between 23/01/2024 and 16/02/2024: %.3g kg\n', mean
(AvgDailyIntake))
fprintf('Median herd intake between 23/01/2024 and 16/02/2024: %.3g kg\n', median
(AvgDailyIntake))

% Combine data by AnimalName and Date, summing IntakeMass for each day
CombinedData = groupsummary(Data, {'AnimalName', 'Date'}, 'sum', 'IntakeKg');

% Rename the summarised column for clarity
CombinedData.Properties.VariableNames{'sum_IntakeKg'} = 'TotalIntakeKg';

% Order CombinedData by date
CombinedData = sortrows(CombinedData, 'Date');

% Identify and count instances with zero intake
zerointake = CombinedData(CombinedData.TotalIntakeKg == 0, :);
instances = height(zerointake);

% Display the number of instances removed due to zero intake
fprintf('Number of intake instances removed due to zero intake: %d\n', instances);

% Remove instances with zero intake from CombinedData
```

```
CombinedData = CombinedData(CombinedData.TotalIntakeKg > 0, :);

%% Plot average intake mass against date for the herd
% Create a box and whisker plot for TotalIntakeKg by Date
figure;
boxchart(categorical(CombinedData.Date), CombinedData.TotalIntakeKg);
hold on;
yline(0.876, '--k', 'LineWidth', 1.2);
yline(0.828, '--k', 'LineWidth', 1.2);
ylim([0, 1]);
xlabel('Date'); ylabel('Total Intake Mass (Kg)');
% title('Box and Whisker Plot of Total Intake Mass by Date');
legend('Animal Daily Intake', 'Maximum Mass Delivery: 0.876 kg', 'Minimum Mass Delivery: 0.828 kg', 'Location', 'best');
grid on;
hold off;

%% Summary Table of Results Shown in the Boxplot
Summary = groupsummary(CombinedData, 'Date', {'mean', 'median', 'min', 'max', 'std'}, 'TotalIntakeKg');

% Rename columns for clarity
Summary.Properties.VariableNames{ 'GroupCount' } = 'n';
Summary.Properties.VariableNames{ 'mean_TotalIntakeKg' } = 'Average Intake (kg)';
Summary.Properties.VariableNames{ 'median_TotalIntakeKg' } = 'Median Intake (kg)';
Summary.Properties.VariableNames{ 'min_TotalIntakeKg' } = 'Minimum Intake (kg)';
Summary.Properties.VariableNames{ 'max_TotalIntakeKg' } = 'Maximum Intake (kg)';
Summary.Properties.VariableNames{ 'std_TotalIntakeKg' } = 'Standard Deviation (kg)';

% Display the summary table
disp('Summary Table of Total Intake Mass by Date:');
disp(Summary);

% Save the summary table as a CSV file
writetable(Summary, 'Cropped_Delivery_Accuracy.csv');

%% End Script
disp('- Script Complete -');
```

```
%% Daily_MooMonitor_Behaviour
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To determine the daily behaviour of the heifers in trial with
% the SSF. Results are broken into total and month-long periods.
%
% Prepared by Bradley Lawrence, October 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Animal Mass Intake, Herd and Individual</strong>\n')

%% Phase Averaging MooMonitor+ data
% Import the data from all three files
File1 = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF - 2023_11_01-2023_12_31 - Org.xlsx", "Sheet1", [2, Inf]);
File2 = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF - 2024_01_01-2024_02_29 - Org.xlsx", "Sheet1", [2, Inf]);
File3 = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF - 2024_03_01-2024_04_30 - Org.xlsx", "Sheet1", [2, Inf]);

% Combine all data
Data = [File1; File2; File3];

% Remove animal IDs [2212 2235 2237 2272 22147]
% Remove animals with extreme data (IDs identified from individual plots)
Remove = [2212 2235 2237 2272 22147];
Data = Data(~ismember(Data.CowId, Remove), :);
animalIds = unique(Data.CowId);
animalIds = rmmissing(animalIds);

% Convert date string to date format
Data.Date = datetime(Data.Date, 'InputFormat', 'dd-MMM-yyyy');

% Check if the number of rows is a multiple of three
if mod(height(Data), 3) ~= 0
    error('Number of rows in raw data file is not a multiple of three');
end

% Create a time vector from 00:00 to 23:45 with 15-minute increments
start = duration(0, 0, 0);
finish = duration(23, 45, 0);
timeofday = start:minutes(15):finish;

n = height(Data);
```

```
% Sequence representing each data category
Sequence1 = 1:3:n;
Sequence2 = 2:3:n;
Sequence3 = 3:3:n;

% Extraction of data types
rumination = Data(Sequence1, :);
resting = Data(Sequence2, :);
feeding = Data(Sequence3, :);

% Phase total and average each behaviour type for the overall data
Rumination = table2array(mean(rumination(:, 5:end)));
Resting = table2array(mean(resting(:, 5:end)));
Feeding = table2array(mean(feeding(:, 5:end)));
Misc = (ones(1,96).*15) - Rumination - Resting - Feeding;

% Convert behaviour to percentage based results
Rumination = 100*((Rumination)./15);
Resting = 100*((Resting)./15);
Feeding = 100*((Feeding)./15);
Misc = 100*((Misc)./15);

% Overall plot
figure(1);
plot(timeofday, Rumination, 'LineWidth', 1, 'DisplayName', 'Rumination')
hold on
plot(timeofday, Resting, 'LineWidth', 1, 'DisplayName', 'Resting')
plot(timeofday, Feeding, 'LineWidth', 1, 'DisplayName', 'Feeding')
plot(timeofday, Misc, 'LineWidth', 1, 'DisplayName', 'Miscellaneous')
hold off
% title('Cumulative Daily Behaviour across testing period')
xlabel('Time of Day (hour)'); ylabel('Activity Time (%)')
ylim([0, 100]); xticks(duration(0:1:24, 0, 0)); xtickformat('hh:mm')
legend('Location', 'best')
grid on
hold off

%% Split data by month and plot separately
months = unique(month(Data.Date)); % Get unique months
month_names = month(datetime(1,months,1), 'name'); % Get month names using datetime

% Pre-allocate stat recording
stats = NaN(4, length(months));

for i = 1:length(months)

    m = months(i);

    % Get data for the current month
```

```
monthi = Data(month(Data.Date) == m, :);

% Determine the row indices for rumination, resting, and feeding
n = height(monthi);
Sequence1 = 1:3:n;
Sequence2 = 2:3:n;
Sequence3 = 3:3:n;

% Extract data types for the current month
rumination = monthi(Sequence1, :);
resting = monthi(Sequence2, :);
feeding = monthi(Sequence3, :);

% Calculate averages for each behavior type
Rumination = table2array(mean(rumination(:, 5:end)));
Resting = table2array(mean(resting(:, 5:end)));
Feeding = table2array(mean(feeding(:, 5:end)));
Misc = (ones(1, 96).*15) - Rumination - Resting - Feeding;

% Provide generic stats for total times performing each activity
stats(:, i) = [sum(Rumination); sum(Resting); sum(Feeding); sum(Misc)];

% Convert behaviour to percentage based results
Rumination = 100*((Rumination)./15);
Resting = 100*((Resting)./15);
Feeding = 100*((Feeding)./15);
Misc = 100*((Misc)./15);

% Plot the data for the current month
figure
plot(timeofday, Rumination, 'LineWidth', 1, 'DisplayName', 'Rumination')
hold on
plot(timeofday, Resting, 'LineWidth', 1, 'DisplayName', 'Resting')
plot(timeofday, Feeding, 'LineWidth', 1, 'DisplayName', 'Feeding')
plot(timeofday, Misc, 'LineWidth', 1, 'DisplayName', 'Miscellaneous')
hold off
title(['Cumulative Daily Behaviour for ', month(datetime(1, m, 1), 'name')])
xlabel('Time of Day'); ylabel('Activity Time (%)')
ylim([0, 100]); xticks(duration(0:1:24, 0, 0)); xtickformat('hh:mm')
legend('Location', 'best')
grid on
hold off
end

%% Conclude Script
disp('- Script Complete -')
```

```
%% Data_Validation
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To validate the data which is imported into matlab maintains
% quality from the data files.
%
% Prepared by Bradley Lawrence, June 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Data Validation</strong>\n')

%% Validate Location Data
LocationData = EquipLocation("Feeder_Data\GPS_Tracker\Equipment Tracking (ELT012)-
data-May 07 2024 11_39_33.csv", [2, Inf]);

% Assess the size of imported data
ImportSize = size(LocationData);
fprintf('LocationData contains %d rows and %d columns\n', ImportSize(1), ImportSize
(2))

% Identify what proportion of data was incorrectly imported. ie missing
% Time
MissingData = sum(ismissing(LocationData.Time));
Missing = (MissingData ./ height(LocationData)) * 100;
fprintf('%.2g percent of LocationData.Time data is missing\n', Missing)

% Latitude
MissingData = sum(isnan(LocationData.Latitude));
Missing = (MissingData ./ height(LocationData)) * 100;
fprintf('%.2g percent of LocationData.Latitude data is missing\n', Missing)

% Longitude
MissingData = sum(isnan(LocationData.Longitude));
Missing = (MissingData ./ height(LocationData)) * 100;
fprintf('%.2g percent of LocationData.Longitude data is missing\n', Missing)

fprintf('\n')

%% Validate MooMonitor+ Data 1
Collar1 = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF -
2023_11_01-2023_12_31 - Org.xlsx", "Sheet1", [2, Inf]);

% Assess the size of imported data
ImportSize = size(Collar1);
fprintf('Collar1 contains %d rows and %d columns\n', ImportSize(1), ImportSize(2))
```

```
% Identify what proportion of data was incorrectly imported. ie missing
% CowId
MissingData = sum(isnan(Collar1.CowId));
Missing = (MissingData ./ height(Collar1)) * 100;
fprintf('%.2g percent of Collar1.CowId data is missing\n', Missing)

% Date
MissingData = sum(ismissing(Collar1.Date));
Missing = (MissingData ./ height(Collar1)) * 100;
fprintf('%.2g percent of Collar1.Date data is missing\n', Missing)

% Behaviour
MissingData = sum(ismissing(Collar1.Behaviour));
Missing = (MissingData ./ height(Collar1)) * 100;
fprintf('%.2g percent of Collar1.Behaviour data data is missing\n', Missing)

% Daily_Total
MissingData = sum(isnan(Collar1.Daily_Total));
Missing = (MissingData ./ height(Collar1)) * 100;
fprintf('%.2g percent of Collar1.Daily_Total data is missing\n', Missing)

fprintf('\n')

%% Validate MooMonitor+ Data 2
Collar2 = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF - 2024_01_01-2024_02_29 - Org.xlsx", "Sheet1", [2, Inf]);

% Assess the size of imported data
ImportSize = size(Collar2);
fprintf('Collar2 contains %d rows and %d columns\n', ImportSize(1), ImportSize(2))

% Identify what proportion of data was incorrectly imported. ie missing
% CowId
MissingData = sum(isnan(Collar2.CowId));
Missing = (MissingData ./ height(Collar2)) * 100;
fprintf('%.2g percent of Collar2.CowId data is missing\n', Missing)

% Date
MissingData = sum(ismissing(Collar2.Date));
Missing = (MissingData ./ height(Collar2)) * 100;
fprintf('%.2g percent of Collar2.Date data is missing\n', Missing)

% Behaviour
MissingData = sum(ismissing(Collar2.Behaviour));
Missing = (MissingData ./ height(Collar2)) * 100;
fprintf('%.2g percent of Collar2.Behaviour data data is missing\n', Missing)

% Daily_Total
```

```
MissingData = sum(isnan(Collar2.Daily_Total));
Missing = (MissingData ./ height(Collar2)) * 100;
fprintf('%.2g percent of Collar2.Daily_Total data is missing\n', Missing)

fprintf('\n')

%% Validate MooMonitor+ Data 3
Collar3 = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF - 2024_03_01-2024_04_30 - Org.xlsx", "Sheet1", [2, Inf]);

% Assess the size of imported data
ImportSize = size(Collar3);
fprintf('Collar3 contains %d rows and %d columns\n', ImportSize(1), ImportSize(2))

% Identify what proportion of data was incorrectly imported. ie missing
% CowId
MissingData = sum(isnan(Collar3.CowId));
Missing = (MissingData ./ height(Collar3)) * 100;
fprintf('%.2g percent of Collar3.CowId data is missing\n', Missing)

% Date
MissingData = sum(ismissing(Collar3.Date));
Missing = (MissingData ./ height(Collar3)) * 100;
fprintf('%.2g percent of Collar3.Date data is missing\n', Missing)

% Behaviour
MissingData = sum(ismissing(Collar3.Behaviour));
Missing = (MissingData ./ height(Collar3)) * 100;
fprintf('%.2g percent of Collar3.Behaviour data data is missing\n', Missing)

% Daily_Total
MissingData = sum(isnan(Collar3.Daily_Total));
Missing = (MissingData ./ height(Collar3)) * 100;
fprintf('%.2g percent of Collar3.Daily_Total data is missing\n', Missing)

fprintf('\n')

%% Validate Intake Mass Data 1
% Import intake mass data using the relevant function file
IntakeData = IntakeMassData("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-05-02 - tray - visits.csv", [2, inf]);

% Assess the size of imported data
ImportSize = size(IntakeData);
fprintf('IntakeData contains %d rows and %d columns\n', ImportSize(1), ImportSize(2))

% Identify what proportion of data was incorrectly imported. ie missing
% FeederTray
MissingData = sum(ismissing(IntakeData.FeederTray));
```

```
Missing = (MissingData ./ height(IntakeData)) * 100;
fprintf('%.2g percent of IntakeData.FeederTray data is missing\n', Missing)

% AnimalName
MissingData = sum(isnan(IntakeData.AnimalName));
Missing = (MissingData ./ height(IntakeData)) * 100;
fprintf('%.2g percent of IntakeData.AnimalName data is missing\n', Missing)

% AnimalTag
MissingData = sum(isnan(IntakeData.AnimalTag));
Missing = (MissingData ./ height(IntakeData)) * 100;
fprintf('%.2g percent of IntakeData.AnimalTag data is missing\n', Missing)

% Date
MissingData = sum(ismissing(IntakeData.Date));
Missing = (MissingData ./ height(IntakeData)) * 100;
fprintf('%.2g percent of IntakeData.Date data is missing\n', Missing)

% IntakeKg
MissingData = sum(isnan(IntakeData.IntakeKg));
Missing = (MissingData ./ height(IntakeData)) * 100;
fprintf('%.2g percent of IntakeData.IntakeKg data is missing\n', Missing)

fprintf('\n')

%% Validate Intake Mass Data 2
IntakeData2 = SSFData2("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-05-02 - tray - visits - 2.csv", [2, inf]);

% Assess the size of imported data
ImportSize = size(IntakeData2);
fprintf('IntakeData2 contains %d rows and %d columns\n', ImportSize(1), ImportSize(2))

% Identify what proportion of data was incorrectly imported. ie missing
% AnimalTag
MissingData = sum(isnan(IntakeData2.AnimalTag));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.AnimalTag data is missing\n', Missing)

% Feeder
MissingData = sum(isnan(IntakeData2.Feeder));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.Feeder data is missing\n', Missing)

% StartTime
MissingData = sum(ismissing(IntakeData2.StartTime));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.StartTime data is missing\n', Missing)
```

```
% EndTime
MissingData = sum(ismissing(IntakeData2.EndTime));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.EndTime data is missing\n', Missing)

% DurationSec
MissingData = sum(ismissing(IntakeData2.EndTime));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.EndTime data is missing\n', Missing)

% StartMassKg
MissingData = sum(isnan(IntakeData2.StartMassKg));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.StartMassKg data is missing\n', Missing)

% EndMassKg
MissingData = sum(isnan(IntakeData2.EndMassKg));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.EndMassKg data is missing\n', Missing)

% MassDiffKg
MissingData = sum(isnan(IntakeData2.MassDiffKg));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.MassDiffKg data is missing\n', Missing)

% Tray
MissingData = sum(isnan(IntakeData2.Tray));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.Tray data is missing\n', Missing)

% FeedType
MissingData = sum(isnan(IntakeData2.FeedType));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.FeedType data is missing\n', Missing)

% Flags
MissingData = sum(ismissing(IntakeData2.Flags));
Missing = (MissingData ./ height(IntakeData2)) * 100;
fprintf('%.2g percent of IntakeData2.Flags data is missing\n', Missing)

fprintf('\n')

%% Validate RFID Data 1
RFIDDataDec = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfid - 2023-12-01_2023-12-31.
csv", [2, Inf]);

% Assess the size of imported data
ImportSize = size(RFIDDataDec);
```

```
fprintf('RFIDDataDec contains %d rows and %d columns\n', ImportSize(1), ImportSize(2))

% Identify what proportion of data was incorrectly imported. ie missing
% ScanTime
MissingData = sum(ismissing(RFIDDataDec.ScanTime));
Missing = (MissingData ./ height(RFIDDataDec)) * 100;
fprintf('%.2g percent of RFIDDataDec.ScanTime Data is missing\n', Missing)

% CowTag
MissingData = sum(isnan(RFIDDataDec.CowTag));
Missing = (MissingData ./ height(RFIDDataDec)) * 100;
fprintf('%.2g percent of RFIDDataDec.CowTag Data is missing\n', Missing)

% InOrOut
MissingData = sum(ismissing(RFIDDataDec.InOrOut));
Missing = (MissingData ./ height(RFIDDataDec)) * 100;
fprintf('%.2g percent of RFIDDataDec.InOrOut Data is missing\n', Missing)

% TrayIfApplicable
MissingData = sum(isnan(RFIDDataDec.TrayIfApplicable));
Missing = (MissingData ./ height(RFIDDataDec)) * 100;
fprintf('%.2g percent of RFIDDataDec.TrayIfApplicable Data is missing\n', Missing)

fprintf('\n')

%% Validate RFID Data 2
RFIDDataJan = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfids - 2024-01-01_2024-01-31.csv", [2, Inf]);

% Assess the size of imported data
ImportSize = size(RFIDDataJan);
fprintf('RFIDDataJan contains %d rows and %d columns\n', ImportSize(1), ImportSize(2))

% Identify what proportion of data was incorrectly imported. ie missing
% ScanTime
MissingData = sum(ismissing(RFIDDataJan.ScanTime));
Missing = (MissingData ./ height(RFIDDataJan)) * 100;
fprintf('%.2g percent of RFIDDataJan.ScanTime Data is missing\n', Missing)

% CowTag
MissingData = sum(isnan(RFIDDataJan.CowTag));
Missing = (MissingData ./ height(RFIDDataJan)) * 100;
fprintf('%.2g percent of RFIDDataJan.CowTag Data is missing\n', Missing)

% InOrOut
MissingData = sum(ismissing(RFIDDataJan.InOrOut));
Missing = (MissingData ./ height(RFIDDataJan)) * 100;
```

```
fprintf('%.2g percent of RFIDDataJan.InOrOut Data is missing\n', Missing)

% TrayIfApplicable
MissingData = sum(isnan(RFIDDataJan.TrayIfApplicable));
Missing = (MissingData ./ height(RFIDDataJan)) * 100;
fprintf('%.2g percent of RFIDDataJan.TrayIfApplicable Data is missing\n', Missing)

fprintf('\n')

%% Validate RFID Data 3
RFIDDataFeb = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfid - 2024-02-01_2024-02-29.
csv", [2, Inf]);

% Assess the size of imported data
ImportSize = size(RFIDDataFeb);
fprintf('RFIDDataFeb contains %d rows and %d columns\n', ImportSize(1), ImportSize
(2))

% Identify what proportion of data was incorrectly imported. ie missing
% ScanTime
MissingData = sum(ismissing(RFIDDataFeb.ScanTime));
Missing = (MissingData ./ height(RFIDDataFeb)) * 100;
fprintf('%.2g percent of RFIDDataFeb.ScanTime Data is missing\n', Missing)

% CowTag
MissingData = sum(isnan(RFIDDataFeb.CowTag));
Missing = (MissingData ./ height(RFIDDataFeb)) * 100;
fprintf('%.2g percent of RFIDDataFeb.CowTag Data is missing\n', Missing)

% InOrOut
MissingData = sum(ismissing(RFIDDataFeb.InOrOut));
Missing = (MissingData ./ height(RFIDDataFeb)) * 100;
fprintf('%.2g percent of RFIDDataFeb.InOrOut Data is missing\n', Missing)

% TrayIfApplicable
MissingData = sum(isnan(RFIDDataFeb.TrayIfApplicable));
Missing = (MissingData ./ height(RFIDDataFeb)) * 100;
fprintf('%.2g percent of RFIDDataFeb.TrayIfApplicable Data is missing\n', Missing)

fprintf('\n')

%% Validate RFID Data 4
RFIDDataMar = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfid - 2024-03-01_2024-03-31.
csv", [2, Inf]);

% Assess the size of imported data
ImportSize = size(RFIDDataMar);
fprintf('RFIDDataMar contains %d rows and %d columns\n', ImportSize(1), ImportSize
(2))
```

```
% Identify what proportion of data was incorrectly imported. ie missing
% ScanTime
MissingData = sum(ismissing(RFIDDataMar.ScanTime));
Missing = (MissingData ./ height(RFIDDataMar)) * 100;
fprintf('%.2g percent of RFIDDataMar.ScanTime Data is missing\n', Missing)

% CowTag
MissingData = sum(isnan(RFIDDataMar.CowTag));
Missing = (MissingData ./ height(RFIDDataMar)) * 100;
fprintf('%.2g percent of RFIDDataMar.CowTag Data is missing\n', Missing)

% InOrOut
MissingData = sum(ismissing(RFIDDataMar.InOrOut));
Missing = (MissingData ./ height(RFIDDataMar)) * 100;
fprintf('%.2g percent of RFIDDataMar.InOrOut Data is missing\n', Missing)

% TrayIfApplicable
MissingData = sum(isnan(RFIDDataMar.TrayIfApplicable));
Missing = (MissingData ./ height(RFIDDataMar)) * 100;
fprintf('%.2g percent of RFIDDataMar.TrayIfApplicable Data is missing\n', Missing)

fprintf('\n')

%% Validate RFID Data 5
RFIDDataApr = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfid - 2024-04-01_2024-04-30.
csv", [2, Inf]);

% Assess the size of imported data
ImportSize = size(RFIDDataApr);
fprintf('RFIDDataApr contains %d rows and %d columns\n', ImportSize(1), ImportSize
(2))

% Identify what proportion of data was incorrectly imported. ie missing
% ScanTime
MissingData = sum(ismissing(RFIDDataApr.ScanTime));
Missing = (MissingData ./ height(RFIDDataApr)) * 100;
fprintf('%.2g percent of RFIDDataApr.ScanTime Data is missing\n', Missing)

% CowTag
MissingData = sum(isnan(RFIDDataApr.CowTag));
Missing = (MissingData ./ height(RFIDDataApr)) * 100;
fprintf('%.2g percent of RFIDDataApr.CowTag Data is missing\n', Missing)

% InOrOut
MissingData = sum(ismissing(RFIDDataApr.InOrOut));
Missing = (MissingData ./ height(RFIDDataApr)) * 100;
fprintf('%.2g percent of RFIDDataApr.InOrOut Data is missing\n', Missing)
```

```
% TrayIfApplicable
MissingData = sum(isnan(RFIDDataApr.TrayIfApplicable));
Missing = (MissingData ./ height(RFIDDataApr)) * 100;
fprintf('%.2g percent of RFIDDataApr.TrayIfApplicable Data is missing\n', Missing)

fprintf('\n')

%% End Script
disp('- Script Complete -');
```

```
%% Equipment_Heatmap
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To generate a heatmap of feeder locations across the trial
% period.
%
% Prepared by Bradley Lawrence, July 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>SSF Heatmap</strong>\n')

%% Import Data
% Modify the file path to your specific CSV file
Data = EquipLocation("Feeder_Data\GPS_Tracker\Equipment Tracking " + ...
    "(ELT012)-data-May 07 2024 11_39_33.csv", [2, Inf]);

%% Extract relevant data
Lat = Data.Latitude;
Lon = Data.Longitude;

% Convert the 'Time' data to datetime
Date = datetime(Data.Time, "InputFormat", "MMM dd yyyy HH:mm:ss");

% Ensure that Lat, Lon, and Date have the same number of elements
if numel(Lat) ~= numel(Lon) || numel(Lat) ~= numel(Date)
    error('Latitude, Longitude, and Date values must have the same number of
elements.');
```

```
end

% Calculate time in days
timeindays = days(Date - Date(1));

%% Geoscatter Plot with Map Background and Time in Days
figure
geoscatter(Lat, Lon, 100, timeindays, 'filled', 'Marker', 'o', 'MarkerFaceAlpha', 0.5);
title('Feeder Locations with Time in Days on a Satellite Basemap')
colorbar
ylabel(colorbar, 'Days Since Start of Trial')

% Add satellite map background
geobasemap('satellite')

%% Conclude Script
disp('- Script Complete -')
```



```
%% Individual_Moomonitor_Plotting
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To plot individual daily total rumination, resting and feeding behaviour
for
% individual animals.
%
% Prepared by Bradley Lawrence, August 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Individual Moomonitor Plotting</strong>\n')

%% MooMonitor Collar Data imported using the import wizards generated function
% Import the data from all three files
File1 = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF -
2023_11_01-2023_12_31 - Org.xlsx", "Sheet1", [2, Inf]);
File2 = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF -
2024_01_01-2024_02_29 - Org.xlsx", "Sheet1", [2, Inf]);
File3 = MooMonitorData("Feeder_Data\MooMonitor_Data\MooMonitor Raw Data TDRF -
2024_03_01-2024_04_30 - Org.xlsx", "Sheet1", [2, Inf]);
% Remove the first row of data from the data set. This row is a title
% row.
File1(1, :) = []; File2(1, :) = []; File3(1, :) = [];

% Combine all data
Data = [File1; File2; File3];

% Convert date string to date format
Data.Date = datetime(Data.Date, 'InputFormat', 'dd-MMM-yyyy');

% Remove all data from the 17th of February 2024 and onwards
Data = Data(Data.Date < datetime('17-Feb-2024', 'InputFormat', 'dd-MMM-yyyy'), :);

%% Check if the number of rows is a multiple of three
if mod(height(Data), 3) ~= 0
    error('Number of rows in raw data file is not a multiple of three');
end

%% Extraction of data for individual animals
% Identifying animal numbers
CowIdi = unique(Data.CowId);
Herd_Size = length(CowIdi);

% Extract individual animal data using logical indexing
```

```
for i = 1:Herd_Size
    Cowi = Data(Data.CowId == CowIdi(i), :);
    n = height(Cowi);

    % Sequence representing each data category
    Sequence1 = 1:3:n;
    Sequence2 = 2:3:n;
    Sequence3 = 3:3:n;

    % Extraction of data types
    rumination = Cowi(Sequence1, :);
    resting = Cowi(Sequence2, :);
    feeding = Cowi(Sequence3, :);

    % Extract date for relevant animal. NB. Rumination_Data is used here
    % however this date is relevant for resting and feeding as well.
    Date = rumination.Date;

    % Extract relevant columns as arrays
    rumination_totals = rumination.Daily_Total;
    resting_totals = resting.Daily_Total;
    feeding_totals = feeding.Daily_Total;

    % Plot results for specific animal
    fig = figure('visible', 'off'); % Because so many figures are being produced I
only want to review them laterplot(rumination_data.Date, rumination_totals,
resting_data.Date, resting_totals, feeding_data.Date, feeding_totals)
    plot(Date, rumination_totals)
    hold on
    plot(Date, resting_totals)
    plot(Date, feeding_totals)
    title(['Behavioural Patterns for Animal ', num2str(CowIdi(i))]);
    xlabel('Day'); ylabel('Time (minutes)')
    legend('Rumination', 'Resting', 'Feeding')
    grid on
    hold off

    % Save figure to file explorer
    filename = fullfile('Figures/Individual_Moomonitor_Results', sprintf
('Behavioural_Movements_%d.jpeg', CowIdi(i)));
    saveas(fig, filename, 'jpeg');

    close(fig)

    fprintf('Cow %d of %d complete\n', i, Herd_Size)

end

disp('- Script Complete -')
```



```
%% Interaction_Statistics_2
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To determine interaction statistics for the SSF
%
% Prepared by Bradley Lawrence, September 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>SSF Inkate Mass</strong>\n')

%% Import Data from previous script
HIT = readtable('HourlyInteractionsTable.csv');

%% Compare average Interactions for the entire herd
% Remove Column 1
HIT = removevars(HIT, 1);
HIM = table2array(HIT);
% Calculate statistics
HIMean = mean(HIM, 1);
HIMedian = median(HIM, 1);

% Plot average and median herd results
figure(1)
bar(0:23, HIMean)
title('Mean Herd interaction behaviour over the course of a day')
xlabel('Time of Day (hr)')
ylabel('Number of Interactions')

figure(2)
bar(0:23, HIMedian)
title('Median Herd interaction behaviour over the course of a day')
xlabel('Time of Day (hr)')
ylabel('Number of Interactions')

% Plot box plots of herd interaction behaviour
figure(3)
boxplot(HIM) %,'PlotStyle','compact')

% title('Herd interaction behaviour expressed over a day')
xlabel('Time of Day (hr)')
ylabel('Number of Interactions')

% Calculate statistics
means = mean(HIM);
medians = median(HIM);
```

```
stddevs = std(HIM);
Min = min(HIM);
Max = max(HIM);

% Generate row names for each hour (Hour_0 to Hour_23)
Row = arrayfun(@(x) sprintf('Hour_%d', x), 0:23, 'UniformOutput', false);

% Create table summarising the results
Summary = table(means', medians', stddevs', Min', Max', 'VariableNames', {'Mean', 'Median', 'StdDev', 'Min', 'Max'}, 'RowNames', Row);

% Print the summary table
writetable(Summary, 'InteractionSummaryTable.csv', 'WriteRowNames', true);

%% Conclude Script
disp('- Script Complete -')
```

```
%% Interaction_Statistics
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To determine interaction statistics for the SSF and prepare data
% for further investigations.
%
% Prepared by Bradley Lawrence, September 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>SSF Inkate Mass</strong>\n')

%% Import data using the import wizard
% Import the data
Data = SSFData2("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-05-02 -
tray - visits - 2.csv", [2, inf]);

% Check that during feeding events no mass is left behind
leftovers = sum(Data.EndMassKg);
if leftovers == 0
    disp('No feed is left behind')
else
    error('Feed is left behind')
end

% Remove columns which are not nessecary
Data = removevars(Data, {'Feeder', 'DurationSec', 'StartMassKg', 'EndMassKg',
'FeedType', 'Flags'});

% Ensure plot saving directory exists, if not create the correct directory
if ~exist('Figures/Daily_Interaction_Frequency', 'dir')
    mkdir('Figures/Daily_Interaction_Frequency');
end

%% Convert to Date-Time format
Data.StartTime = datetime(Data.StartTime, 'InputFormat', 'dd/MM/yyyy HH:mm');
Data.EndTime = datetime(Data.EndTime, 'InputFormat', 'dd/MM/yyyy HH:mm');

% Create an array of all days with data
FirstDay = datetime('05-Dec-2023', 'InputFormat', 'dd-MMM-yyyy');
LastDay = datetime('02-May-2024', 'InputFormat', 'dd-MMM-yyyy');
Days = FirstDay>LastDay;

% Identify unique animal IDs
UniqueIDs = unique(Data.AnimalTag);
```

```
% Sort Data by animal Tag, note that feeder trays are not combined
% as each interaction is valuable.

% Extract the time part from the StartTime or EndTime
Data.StartTimeOfDay = timeofday(Data.StartTime);

% Sort by StartTimeOfDay
Data = sortrows(Data, 'StartTimeOfDay');

% Initialise the table to store hourly interactions (rows: animals, columns: hours)
HourLabels = cell(1, 24); % Preallocate cell array
for i = 0:23
    HourLabels{i+1} = sprintf('Hour_%d', i);
end
HourlyInteractionsTable = array2table(zeros(length(UniqueIDs), 24), 'VariableNames', \
HourLabels);

% Fill the table with interaction data
for i = 1:length(UniqueIDs)
    Cow = UniqueIDs(i);

    % Filter data for the current cow
    CowData = Data(Data.AnimalTag == Cow, :);

    % Extract the hour of day from the StartTime
    CowData.HourOfDay = hour(CowData.StartTime);

    % Count interactions for each hour of the day (0 to 23)
    for h = 0:23
        HourlyInteractionsTable{i, h+1} = sum(CowData.HourOfDay == h);
    end

    % Plot interactions for each cow
    fig = figure('Visible','off');
    bar(0:23, HourlyInteractionsTable{i, :});
    title(['Interactions per Hour for RFID: ', num2str(Cow)]);
    xlabel('Hour of Day');
    ylabel('Number of Interactions');
    xticks(0:23); % Label each hour
    grid on;

    % Save the plot for cow i
    saveas(fig, ['Figures/Daily_Interaction_Frequency/Cow_', num2str(Cow), \
'_Interactions_Per_Hour.png']);
    close(fig)

    fprintf('Cow %d of %d complete\n', i, length(UniqueIDs))
end
```

```
% Add Animal IDs as row names
HourlyInteractionsTable.AnimalID = UniqueIDs;

% Rearrange the table so AnimalID is first column
HourlyInteractionsTable = movevars(HourlyInteractionsTable, 'AnimalID', 'Before', 'Hour_0');

% Filter Data: Only keep 'animals' with >= 1 interaction/hour. This removes
% tests performed by researchers with the system
averages = mean(HourlyInteractionsTable{:, 2:end}, 2);
HIT = HourlyInteractionsTable(averages >= 1, :); % Keep rows where average >= 1

fprintf('Kept %d rows with average >= 1 interaction per hour.\n', size(HIT, 1));

% Save the table to a CSV file
writetable(HIT, 'HourlyInteractionsTable.csv');

%% Conclude Script
disp('- Script Complete -')
```

```
%% Mass_Intake_Statistics
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To determine statistical results for SSF interaction data,
% including for individual trays.
%
% Prepared by Bradley Lawrence, September 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Mass Intake Statistics</strong>\n')

%% Import Intake Mass Data
% Import data using the function created using import wizard
Data = IntakeMassData("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-
05-02 - tray - visits.csv", [2, inf]);
% Remove AnimalTag column
Data = removevars(Data, "AnimalTag");

%% Identify quality of data.
% NaN data includes T1, T2, Auto-Detected, Tag1, Tag2, Tag3 and Tag4 data
MissingData = sum(isnan(Data.AnimalName));
Missing = (MissingData./height(Data)).*100;
fprintf('%.2g percent of mass intake data is missing\n', Missing);

% Remove missing data
Data = rmmissing(Data);

%% Identify animal IDs, remove all non identifiable inputs
% Remove animals from the dataset which have extreme data, as identified
% from script Animal_Mass_Intake_Herd_Individual
Remove = [2212, 2216, 2218, 2245, 2257, 2258, 2263, 2270, 2272, 2274, 2277];
Data = Data(~ismember(Data.AnimalName, Remove), :);

AnimalIds = unique(Data.AnimalName);
AnimalIds = rmmissing(AnimalIds);

%% Preparation of data for processing.
% Modify data into the desired format
% Extract the tray number from the FeederTray column and convert the extracted string
to a numeric value
Data.FeederTray = str2double(extractAfter(Data.FeederTray, "-"));
% Convert date string to date format
Data.Date = datetime(Data.Date, 'InputFormat', 'dd/MM/yyyy');

% Reorder data into date time chronological order.
```

```
Data = sortrows(Data, "Date");

% Aggregate data by day
DailyData = groupsummary(Data, 'Date', 'mean', 'IntakeKg');

% Note that because group summary is an inbuilt function it inadvertently
% counts the number of cows by feeder tray. This is adjusted for below.
DailyData.GroupCount = DailyData.GroupCount./4;
DailyData.mean_IntakeKg = DailyData.mean_IntakeKg.*4;

% Plot the aggregated daily intake
figure(1);
plot(DailyData.Date, DailyData.mean_IntakeKg, '-');
xlabel('Date');
ylabel('Total Mass Intake (kg)');
title('Daily Aggregated Mass Intake');
hold on
plot([datetime('01/01/2024','InputFormat','dd/MM/yyyy'), datetime('04/05/2024','InputFormat','dd/MM/yyyy')], [0.876, 0.876], '-r');
plot([datetime('01/01/2024','InputFormat','dd/MM/yyyy'), datetime('04/05/2024','InputFormat','dd/MM/yyyy')], [0.828, 0.828], '-r');
hold off

%% Split data according to feeder trays
% split data and accumulate mean daily values
Tray1 = Data(Data.FeederTray == 1, :);
Tray2 = Data(Data.FeederTray == 2, :);
Tray3 = Data(Data.FeederTray == 3, :);
Tray4 = Data(Data.FeederTray == 4, :);

DailyTray1 = groupsummary(Tray1, 'Date', 'mean', 'IntakeKg');
DailyTray2 = groupsummary(Tray2, 'Date', 'mean', 'IntakeKg');
DailyTray3 = groupsummary(Tray3, 'Date', 'mean', 'IntakeKg');
DailyTray4 = groupsummary(Tray4, 'Date', 'mean', 'IntakeKg');

% Plot results
figure(2)
subplot(2, 2, 1)
plot(DailyTray1.Date, DailyTray1.mean_IntakeKg)
title('Tray 1')
xlabel('Date'); ylabel('Mass Intake (kg)');
subplot(2, 2, 2)
plot(DailyTray2.Date, DailyTray2.mean_IntakeKg)
title('Tray 2')
xlabel('Date'); ylabel('Mass Intake (kg)');
subplot(2, 2, 3)
plot(DailyTray3.Date, DailyTray3.mean_IntakeKg)
title('Tray 3')
xlabel('Date'); ylabel('Mass Intake (kg)');
```

```
subplot(2, 2, 4)
plot(DailyTray4.Date, DailyTray4.mean_IntakeKg)
title('Tray 4')
xlabel('Date'); ylabel('Mass Intake (kg)');

%% Split data according to feeder trays
% Split data and accumulate median daily values
DailyTray1_ = groupsummary(Tray1, 'Date', 'median', 'IntakeKg');
DailyTray2_ = groupsummary(Tray2, 'Date', 'median', 'IntakeKg');
DailyTray3_ = groupsummary(Tray3, 'Date', 'median', 'IntakeKg');
DailyTray4_ = groupsummary(Tray4, 'Date', 'median', 'IntakeKg');

% Plot results
figure(3)
subplot(2, 2, 1)
plot(DailyTray1_.Date, DailyTray1_.median_IntakeKg)
title('Tray 1')
xlabel('Date'); ylabel('Mass Intake (kg)');
subplot(2, 2, 2)
plot(DailyTray2_.Date, DailyTray2_.median_IntakeKg)
title('Tray 2')
xlabel('Date'); ylabel('Mass Intake (kg)');
subplot(2, 2, 3)
plot(DailyTray3_.Date, DailyTray3_.median_IntakeKg)
title('Tray 3')
xlabel('Date'); ylabel('Mass Intake (kg)');
subplot(2, 2, 4)
plot(DailyTray4_.Date, DailyTray4_.median_IntakeKg)
title('Tray 4')
xlabel('Date'); ylabel('Mass Intake (kg)');

% From the Tray comparison plot it can be seen that between 24 Jan and 17
% Feb, all feeder trays are interacted with fairly reliably. This time
% chunk will therefore be assessed below.

Start = datetime('24-Jan-2024');
End = datetime('17-Feb-2024');

% Crop data by the bounds expressed above.
CroppedTray1 = Tray1(Tray1.Date >= Start & Tray1.Date <= End, :);
CroppedTray2 = Tray2(Tray2.Date >= Start & Tray2.Date <= End, :);
CroppedTray3 = Tray3(Tray3.Date >= Start & Tray3.Date <= End, :);
CroppedTray4 = Tray4(Tray4.Date >= Start & Tray4.Date <= End, :);

% Average Daily Intakes across the herd.
figure(4)
subplot(2, 2, 1)
plot(CroppedTray1.Date, CroppedTray1.IntakeKg)
title('Tray 1')
```

```
xlabel('Date'); ylabel('Mass Intake (kg)');
subplot(2, 2, 2)
plot(CroppedTray2.Date, CroppedTray2.IntakeKg)
title('Tray 2')
xlabel('Date'); ylabel('Mass Intake (kg)');
subplot(2, 2, 3)
plot(CroppedTray3.Date, CroppedTray3.IntakeKg)
title('Tray 3')
xlabel('Date'); ylabel('Mass Intake (kg)');
subplot(2, 2, 4)
plot(CroppedTray4.Date, CroppedTray4.IntakeKg)
title('Tray 4')
xlabel('Date'); ylabel('Mass Intake (kg)');

%% Conclude Script
disp('- Script Complete -')
```

```
%% Scan_Times
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To determine how many cattle interact with the smartfeeder at a
% time.
%
% Prepared by Bradley Lawrence, September 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Scan Times</strong>\n')

%% Import Data using the import wizard function
% Import the data
DataDec = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfids - 2023-12-01_2023-12-31.
csv", [2, Inf]);
DataJan = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfids - 2024-01-01_2024-01-31.
csv", [2, Inf]);
DataFeb = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfids - 2024-02-01_2024-02-29.
csv", [2, Inf]);
DataMar = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfids - 2024-03-01_2024-03-31.
csv", [2, Inf]);
DataApr = RFIDData("Feeder_Data\SmartFeed_Data\CSV\rfids - 2024-04-01_2024-04-30.
csv", [2, Inf]);

%% Scan Time formatting is inconsistent, arrange to be consistent and compile data
% Allocate datetime format according to raw data
DataDec.ScanTime = datetime(DataDec.ScanTime, 'InputFormat', 'yyyy-MM-dd HH:mm:ss');
DataJan.ScanTime = datetime(DataJan.ScanTime, 'InputFormat', 'yyyy-MM-dd HH:mm:ss');
DataFeb.ScanTime = datetime(DataFeb.ScanTime, 'InputFormat', 'dd/MM/yyyy HH:mm');
DataMar.ScanTime = datetime(DataMar.ScanTime, 'InputFormat', 'dd/MM/yyyy HH:mm');
DataApr.ScanTime = datetime(DataApr.ScanTime, 'InputFormat', 'yyyy-MM-dd HH:mm:ss');

% Rearrange format for February and March
DataFeb.ScanTime.Format = 'dd-MM-yyyy HH:mm:ss';
DataMar.ScanTime.Format = 'dd-MM-yyyy HH:mm:ss';

% Combine Data into a single file
Data = [DataDec; DataJan; DataFeb; DataMar; DataApr];

%% Check for missing data
MissingCT = sum(isnan(Data.CowTag));
MissingT = sum(isnan(Data.TrayIfApplicable));
if MissingCT ~= 0
    warning('Missing CowTag data')
elseif MissingT ~= 0
```

```
warning('Missing Tray data')
end

%% Add a logical column to the Data set which aligns with In/Out
% Assign 1 for 'In' and -1 for 'Out'
Data.Register = zeros(size(Data.InOrOut));
InID = strcmp(Data.InOrOut, 'In'); % Set 1 where InOrOut is 'In'
Data.Register(InID) = 1; % Update Register for In
OutID = strcmp(Data.InOrOut, 'Out'); % Set -1 where InOrOut is 'Out'
Data.Register(OutID) = -1; % Update Register for In

% Cumulatively sum in/out registers to identify how many animals are in or out
% of the feeder at a time
Data.Interaction = cumsum(Data.Register);

if sum(Data.Register) == 0
    disp('In/Out data is balanced')
else
    warning('In/Out data is imbalanced by %d', sum(Data.Register))
end

% Visualise the data
figure(1)
plot (Data.ScanTime, Data.Interaction, '.')
title('Simultaneous interaction behaviour')
ylabel('No. animals interacting')
xlabel('Time')

% Correct random scan errors by adding/subtracting 1 when Data.Register
% exceeds 4 and goes lower than 0.
Data.Interaction = min(max(Data.Interaction, 0), 4);

figure(2)
plot (Data.ScanTime, Data.Interaction, '.')
title('Simultaneous interaction behaviour')
ylabel('No. animals interacting')
xlabel('Time')

%% Conclude Script
disp('- Script Complete -')
```

```
%% Simutaneous Interactions
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To determine how when and how frequently animals interact
% simultaneously
%
% Prepared by Bradley Lawrence, October 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Simultaneous Interactions</strong>\n')

%% Import data using the import wizard
% Import the data
Data = SSFData2("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-05-02 -
tray - visits - 2.csv", [2, inf]);

% Convert to Date-Time format
Data.StartTime = datetime(Data.StartTime, 'InputFormat', 'dd/MM/yyyy HH:mm');
Data.EndTime = datetime(Data.EndTime, 'InputFormat', 'dd/MM/yyyy HH:mm');

% Identify unique timestamps
Time = unique(Data.StartTime);

% Initialise result table with the Time column
Results = table(Time, zeros(length(Time), 1), 'VariableNames', {'Time', 'Sum'});

%% Identify simultaneous interactions
for i = 1:height(Time)
    % Find rows corresponding to the current unique time
    Rows = Data.StartTime == Time(i);

    % Extract animal tags for those rows
    InteractingAnimals = unique(Data.AnimalTag(Rows));

    % Count how many animals are interacting for this time step
    Count = length(InteractingAnimals);

    % Store animal count in Results
    Results.Sum(i) = Count;
end

%% Plot findings
plot(Results.Time, Results.Sum, '.')
ylim([0 max(Results.Sum)])
yticks(0:1:max(Results.Sum))
```

```
%% Statistical Results
% Count the number of times 1-N animals interact simultaneously
count = zeros(1,max(Results.Sum));
disp('Number of interactions in a minute-long window:')
for n = 1:max(Results.Sum)
    count(n) = sum(Results.Sum == n);
    if n == 1
        fprintf('Times %d animal interacted: %d\n', n, count(n));
    else
        fprintf('Times %d animals interacted: %d\n', n, count(n));
    end
end

%% Percentage of events where each interaction quantity occurs
TotalEvents = sum(count);
fprintf('\nPercentage of events for each interaction quantity:\n');
for n = 1:max(Results.Sum)
    percentage = (count(n) / TotalEvents) * 100;
    if n == 1
        fprintf('%d animal: %.2f%% of events\n', n, percentage);
    else
        fprintf('%d animals: %.2f%% of events\n', n, percentage);
    end
end

%% Conclude Script
disp('- Script Complete -');
```

```
%% SSF Malfunction Analysis
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: To assess major malfunction events encountered while the SSF
% was in trail at the TDRF.
%
% Prepared by Bradley Lawrence, September 2024
% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Mass Intake Statistics</strong>\n')

%% Import Intake Mass Data
Data = IntakeMassData("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-
05-02 - tray - visits.csv", [2, inf]);

% Identify quality of data
MissingData = sum(isnan(Data.AnimalName));
Missing = (MissingData ./ height(Data)) * 100;
fprintf('%2g percent of mass intake data is missing\n', Missing)

% Remove missing data
Data = rmmissing(Data);

% Preparation of data for processing
Data.FeederTray = str2double(extractAfter(Data.FeederTray, "-"));
Data.Date = datetime(Data.Date, 'InputFormat', 'dd/MM/yyyy');
Data = sortrows(Data, "Date");

% Define timeframes
timeframes = struct(...
    'PreT2Offline', [datetime('24/01/2024', 'InputFormat', 'dd/MM/yyyy'), datetime
('17/02/2024', 'InputFormat', 'dd/MM/yyyy')], ...
    'T2Offline', [datetime('18/02/2024', 'InputFormat', 'dd/MM/yyyy'), datetime
('03/04/2024', 'InputFormat', 'dd/MM/yyyy')], ...
    'PostT2Offline', [datetime('04/04/2024', 'InputFormat', 'dd/MM/yyyy'), datetime
('01/05/2024', 'InputFormat', 'dd/MM/yyyy')]);

% Initialise containers for intake data
IntakeData = struct();

for tray = 1:4
    for timeframe = fieldnames(timeframes)'
        % Use indexing to get the start and end dates
        startdate = timeframes.(timeframe{1})(1);
        enddate = timeframes.(timeframe{1})(2);
```

```
% Filter data for the specific tray and timeframe
FilteredData = Data(Data.FeederTray == tray & Data.Date >= startdate & Data.
Date <= enddate, :);
SummaryData = groupsummary(FilteredData, 'Date', 'sum', 'IntakeKg');

% Store total intake and mean intake
IntakeData.(sprintf('Tray%d_%s', tray, timeframe{1})) = SummaryData;
end
end

%% Plot Total Feed Intake for each tray
fig = figure(1);
tile = tiledlayout(2,2);

% Plot Total Feed Intake for Tray 1
nexttile(tile)
hold on
title('Tray 1')
plot(IntakeData.Tray1_PreT2Offline.Date, IntakeData.Tray1_PreT2Offline.sum_IntakeKg, 'b', 'DisplayName', 'Pre-T2 Offline')
plot(IntakeData.Tray1_T2Offline.Date, IntakeData.Tray1_T2Offline.sum_IntakeKg, 'r', 'DisplayName', 'Offline')
plot(IntakeData.Tray1_PostT2Offline.Date, IntakeData.Tray1_PostT2Offline.
sum_IntakeKg, 'g', 'DisplayName', 'Post-T2 Offline')
xlabel('Date'); ylabel('Mass Intake (kg)');
ylim([0 30]);
hold off

% Plot Total Feed Intake for Tray 2
nexttile(tile)
hold on
title('Tray 2')
plot(IntakeData.Tray2_PreT2Offline.Date, IntakeData.Tray2_PreT2Offline.sum_IntakeKg, 'b', 'DisplayName', 'Pre-T2 Offline')
plot(IntakeData.Tray2_T2Offline.Date, IntakeData.Tray2_T2Offline.sum_IntakeKg, 'r', 'DisplayName', 'Offline')
plot(IntakeData.Tray2_PostT2Offline.Date, IntakeData.Tray2_PostT2Offline.
sum_IntakeKg, 'g', 'DisplayName', 'Post-T2 Offline')
xlabel('Date'); ylabel('Mass Intake (kg)');
ylim([0 30]);
hold off

% Plot Total Feed Intake for Tray 3
nexttile(tile)
hold on
title('Tray 3')
plot(IntakeData.Tray3_PreT2Offline.Date, IntakeData.Tray3_PreT2Offline.sum_IntakeKg, 'b', 'DisplayName', 'Pre-T2 Offline')
```

```
plot(IntakeData.Tray3_T2Offline.Date, IntakeData.Tray3_T2Offline.sum_IntakeKg, 'r', 'DisplayName', 'Offline')
plot(IntakeData.Tray3_PostT2Offline.Date, IntakeData.Tray3_PostT2Offline.sum_IntakeKg, 'g', 'DisplayName', 'Post-T2 Offline')
xlabel('Date'); ylabel('Mass Intake (kg)');
ylim([0 30]);
hold off

% Plot Total Feed Intake for Tray 4
nexttile(tile)
hold on
title('Tray 4')
plot(IntakeData.Tray4_PreT2Offline.Date, IntakeData.Tray4_PreT2Offline.sum_IntakeKg, 'b', 'DisplayName', 'Pre-T2 Offline')
plot(IntakeData.Tray4_T2Offline.Date, IntakeData.Tray4_T2Offline.sum_IntakeKg, 'r', 'DisplayName', 'Offline')
plot(IntakeData.Tray4_PostT2Offline.Date, IntakeData.Tray4_PostT2Offline.sum_IntakeKg, 'g', 'DisplayName', 'Post-T2 Offline')
xlabel('Date'); ylabel('Mass Intake (kg)');
ylim([0 30]);
hold off

% Add a single legend below the entire figure
Legend = legend('Pre-T2 Offline', 'T2 Offline', 'Post-T2 Offline');

% Define the location of the legend
Legend.Layout.Tile = 'South';
Legend.Orientation = 'horizontal';

%% Summary boxplot for total mass intake across the feeder trays relative to T2 going offline.
% Initialise the pre, during, and post T2 offline scenarios
scenarios = {'PreT2Offline', 'T2Offline', 'PostT2Offline'};
% Initialise arrays to hold intake data, tray groups and scenario groupings
% (to be used for the x axis)
IntakeDataArr = [];
TrayGroup = [];
ScenarioGroup = [];

% Loop through each tray and scenario
for tray = 1:4
    for s = 1:length(scenarios)
        scenario = scenarios{s};

        % Get the intake data for the current tray and scenario
        IntakeDataCurrent = IntakeData.(sprintf('Tray%d_%s', tray, scenario)).sum_IntakeKg;

        % Append the intake data to the main array
```

```
IntakeDataArr = [IntakeDataArr; IntakeDataCurrent];

% Create grouping labels for scenario and tray
Entries = length(IntakeDataCurrent); % Get number of entries for the current
scenario
ScenarioGroup = [ScenarioGroup; repmat(s, Entries, 1)]; % Numeric grouping
for scenario (1 = Pre, 2 = T2Offline, etc.)
TrayGroup = [TrayGroup; repmat(tray, Entries, 1)]; % Group by tray (1, 2, 3,
or 4)
end
end

% Create grouped boxplot
figure;
h = boxplot(IntakeDataArr, {ScenarioGroup, TrayGroup}, 'FactorSeparator', 1,
'Colors', 'brkg', 'PlotStyle', 'compact');
title('The impact of a system malfunction on herd mass intake. ');
ylabel('Total Herd Mass Intake (kg)');
xtickPositions = [2.5, 6.5, 10.5]; % Calculated based off the number of boxplots
xticks(xtickPositions); % Set x-ticks to the middle of each tray group
xticklabels(scenarios); % Label x-ticks with scenario names

% Create custom legend, required because of the grouped boxplot
hold on;
custom = zeros(4,1);
color = {'b', 'r', 'k', 'g'};
for i = 1:4
    custom(i) = plot(NaN, NaN, 'color', color{i}, 'LineWidth', 2);
end
legend(custom, {'Tray 1', 'Tray 2', 'Tray 3', 'Tray 4'}, 'Location', 'northwest');
hold off;

%% Summary statistics for the data processed.
% Initialise a table for summary statistics
SummaryStats = table();

% Loop through each tray and scenario
for tray = 1:4
    for scenario = scenarios
        % Get the intake data for the current tray and scenario
        IntakeDataCurrent = IntakeData.(sprintf('Tray%d_s', tray, scenario{1})).
sum_IntakeKg;

        % Calculate the summary statistics
        MeanIntake = mean(IntakeDataCurrent);
        MedianIntake = median(IntakeDataCurrent);
        StdIntake = std(IntakeDataCurrent);
        MinIntake = min(IntakeDataCurrent);
        MaxIntake = max(IntakeDataCurrent);
```

```
% Create a new row for the table
Row = {sprintf('Tray %d', tray), scenario{1}, MeanIntake, MedianIntake,
StdIntake, MinIntake, MaxIntake};

% Append the row to the SummaryStats table
SummaryStats = [SummaryStats; Row];
end
end

% Define column names
SummaryStats.Properties.VariableNames = {'FeederTray', 'Condition', 'Mean', 'Median',
'StdDev', 'Min', 'Max'};

% Save the table to a CSV file
writetable(SummaryStats, 'Tray2_Offline_Stats.csv');

%% Conclude Script
disp('- Script Complete -');
```

```
%% Tray_Interactions
% Evaluation of a C-Lock Super SmartFeed trailer for controlled feed
% supplement delivery in grassfed dairy applications.
%
% ENP111 - Professional Engineer Research Project, Year Long, 2024
%
% Purpose: Identify mass intake values and intervals at each feeder tray.
%
% Prepared by Bradley Lawrence, September 2024

% Ensure MATLAB is working with a clean slate
close all; clear; clc
fprintf('<strong>Tray Interactions</strong>\n')

%% Identify the number of delivery events at each tray
% Import intake mass data using the relevant function file
Data = IntakeMassData("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-
05-02 - tray - visits.csv", [2, inf]);

% Remove missing data
Data = rmmissing(Data);

% Preparation of data for processing
Data.FeederTray = str2double(extractAfter(Data.FeederTray, "-"));
Data.Date = datetime(Data.Date, 'InputFormat', 'dd/MM/yyyy');
Data = sortrows(Data, "Date");

%% Tray Separation
% Separate data into each feeder tray
Tray1 = Data(Data.FeederTray == 1, :);
Tray2 = Data(Data.FeederTray == 2, :);
Tray3 = Data(Data.FeederTray == 3, :);
Tray4 = Data(Data.FeederTray == 4, :);

% Plot data to visualise before processing
figure(1)
subplot(2, 2, 1)
plot(Tray1.Date, Tray1.IntakeKg, '.')
title('Tray 1')
xlabel('Date'); ylabel('Mass Delivery (kg)');
subplot(2, 2, 2)
plot(Tray2.Date, Tray2.IntakeKg, '.')
title('Tray 2')
xlabel('Date'); ylabel('Mass Delivery (kg)');
subplot(2, 2, 3)
plot(Tray3.Date, Tray3.IntakeKg, '.')
title('Tray 3')
xlabel('Date'); ylabel('Mass Delivery (kg)');
subplot(2, 2, 4)
```

```
plot(Tray4.Date, Tray4.IntakeKg, '.')
title('Tray 4')
xlabel('Date'); ylabel('Mass Delivery (kg)');

% Split data into two tables based on the 27th of December, the day where
% calibration is updated.
% Define the recalibration date
recalibration = datetime('27/12/2023', 'InputFormat', 'dd/MM/yyyy');

% Separate each tray's data into two groups: pre- and post-recalibration
Pre_T1 = Tray1(Tray1.Date < recalibration, :);
Post_T1 = Tray1(Tray1.Date >= recalibration, :);
Pre_T2 = Tray2(Tray2.Date < recalibration, :);
Post_T2 = Tray2(Tray2.Date >= recalibration, :);
Pre_T3 = Tray3(Tray3.Date < recalibration, :);
Post_T3 = Tray3(Tray3.Date >= recalibration, :);
Pre_T4 = Tray4(Tray4.Date < recalibration, :);
Post_T4 = Tray4(Tray4.Date >= recalibration, :);

%% Calculate unique intake values for each tray and time period
% Identify the unique intake mass values for each tray before and after the
recalibration date
Pre_T1_int = unique(Pre_T1.IntakeKg);
Post_T1_int = unique(Post_T1.IntakeKg);

Pre_T2_int = unique(Pre_T2.IntakeKg);
Post_T2_int = unique(Post_T2.IntakeKg);

Pre_T3_int = unique(Pre_T3.IntakeKg);
Post_T3_int = unique(Post_T3.IntakeKg);

Pre_T4_int = unique(Pre_T4.IntakeKg);
Post_T4_int = unique(Post_T4.IntakeKg);

% Create a buffer so that results can be tabulated together, this is
% necessary because there are varying feed intervals.
% Determine the maximum length of the unique intake values
Upper_Pre = max([length(Pre_T1_int), length(Pre_T2_int), length(Pre_T3_int), length
(Pre_T4_int)]);
Upper_Post = max([length(Post_T1_int), length(Post_T2_int), length(Post_T3_int),
length(Post_T4_int)]);

% Buffer the shorter columns for the pre-recalibration scenario with NaN
Pre_T1_int(end+1:Upper_Pre) = NaN;
Pre_T2_int(end+1:Upper_Pre) = NaN;
Pre_T3_int(end+1:Upper_Pre) = NaN;
Pre_T4_int(end+1:Upper_Pre) = NaN;

% Buffer the shorter columns for the post-recalibration scenario with NaN
```

```
Post_T1_int(end+1:Upper_Post) = NaN;
Post_T2_int(end+1:Upper_Post) = NaN;
Post_T3_int(end+1:Upper_Post) = NaN;
Post_T4_int(end+1:Upper_Post) = NaN;

%% Compile results into tables
% Create a table for the intake values before the recalibration date
Pre = table(Pre_T1_int, Pre_T2_int, Pre_T3_int, Pre_T4_int, 'VariableNames', \
{'Tray1', 'Tray2', 'Tray3', 'Tray4'});

% Create a table for the intake values after the recalibration date
Post = table(Post_T1_int, Post_T2_int, Post_T3_int, Post_T4_int, 'VariableNames', \
{'Tray1', 'Tray2', 'Tray3', 'Tray4'});

%% Write results to CSV files
% Write the 'Pre' table to a CSV file
writetable(Pre, 'Unique_Intake_Pre_Recalibration.csv');

% Write the 'Post' table to a CSV file
writetable(Post, 'Unique_Intake_Post_Recalibration.csv');

%% Import data using the import wizard
% Import the data
Data = SSFData2("Feeder_Data\SmartFeed_Data\CSV\IntakeMass_2023-12-01_to_2024-05-02 - \
tray - visits - 2.csv", [2, inf]);

% Convert to Date-Time format
Data.StartTime = datetime(Data.StartTime, 'InputFormat', 'dd/MM/yyyy HH:mm');
Data.EndTime = datetime(Data.EndTime, 'InputFormat', 'dd/MM/yyyy HH:mm');

% Identify unique timestamps
Time = unique(Data.StartTime);

% Initialise result table with the Time column
Results = table(Time, zeros(length(Time), 1), 'VariableNames', {'Time', 'Sum'});

%% Identify simultaneous interactions
for i = 1:height(Time)
    % Find rows corresponding to the current unique time
    Rows = Data.StartTime == Time(i);

    % Extract animal tags for those rows
    InteractingAnimals = unique(Data.AnimalTag(Rows));

    % Count how many animals are interacting for this time step
    Count = length(InteractingAnimals);

    % Store animal count in Results
    Results.Sum(i) = Count;
end
```

```
end

%% Plot findings
figure(2)
plot(Results.Time, Results.Sum, '.')
ylim([0 max(Results.Sum)])
yticks(0:1:max(Results.Sum))
ylabel('Number of Simultaneous Interactions')
xlabel('Time of Day (hour)');

%% Statistical Results
% Count the number of times 1-N animals interact simultaneously
count = zeros(1,max(Results.Sum));
disp('Number of interactions in a minute-long window:')
for n = 1:max(Results.Sum)
    count(n) = sum(Results.Sum == n);
    if n == 1
        fprintf('Times %d animal interacted: %d\n', n, count(n));
    else
        fprintf('Times %d animals interacted: %d\n', n, count(n));
    end
end

%% Percentage of events where each interaction quantity occurs
TotalEvents = sum(count);
fprintf('\nPercentage of events for each interaction quantity:\n');
for n = 1:max(Results.Sum)
    percentage = (count(n) / TotalEvents) * 100;
    if n == 1
        fprintf('%d animal: %.2f%% of events\n', n, percentage);
    else
        fprintf('%d animals: %.2f%% of events\n', n, percentage);
    end
end

%% Plot Simultaneous interactions
% Extract the time of day for each interaction
time = timeofday(Results.Time);

% Plot simultaneous interactions on a 24-hour time axis
figure(3)
plot(time, Results.Sum, '.')
% title('Simultaneous Interactions Across a 24-Hour Period')
ylabel('Number of Simultaneous Interactions')
xlabel('Time of Day (hour)');
ylim([0, 6]); xticks(duration(0:1:24, 0, 0)); xtickformat('hh:mm')
grid on

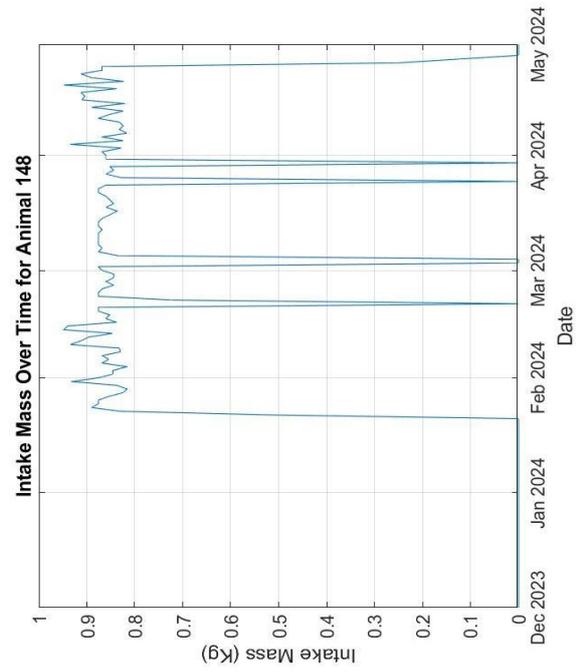
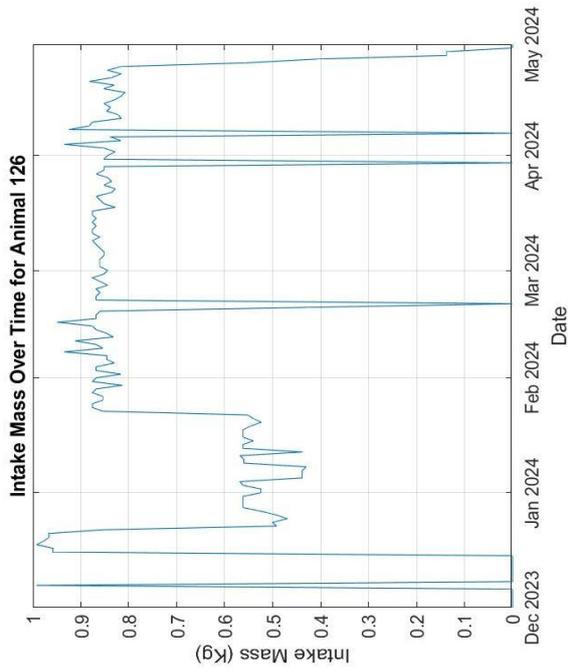
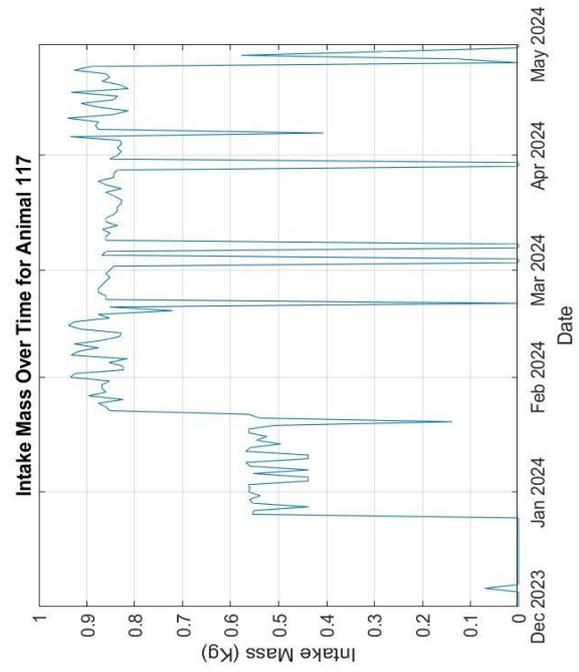
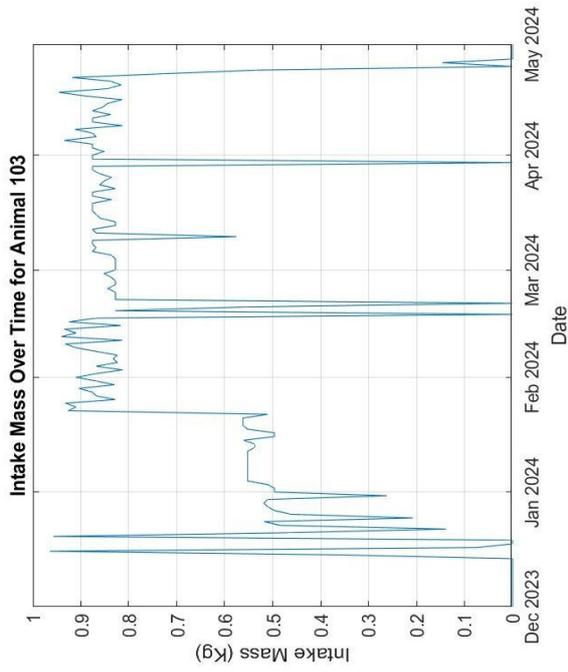
%% Conclude Script
```

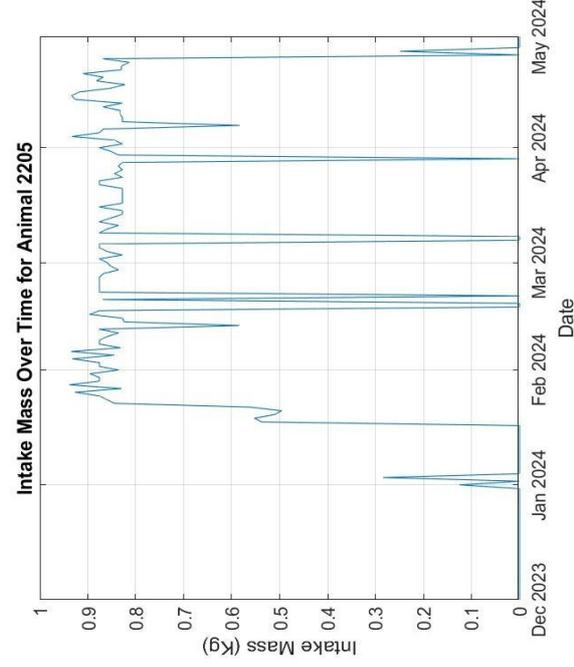
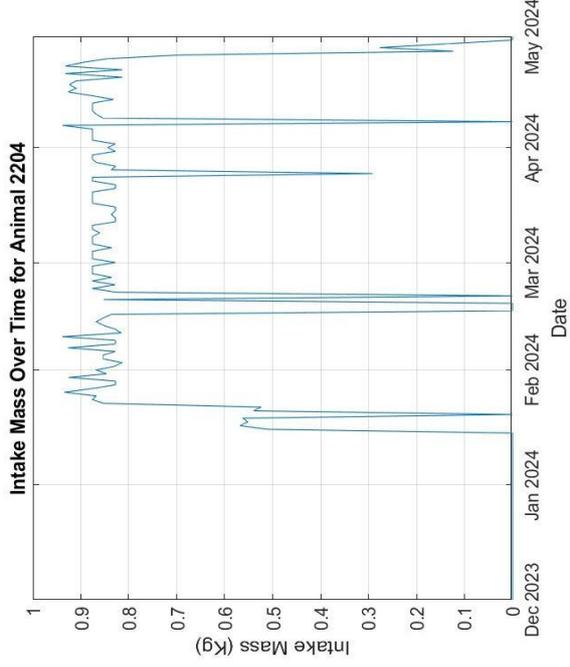
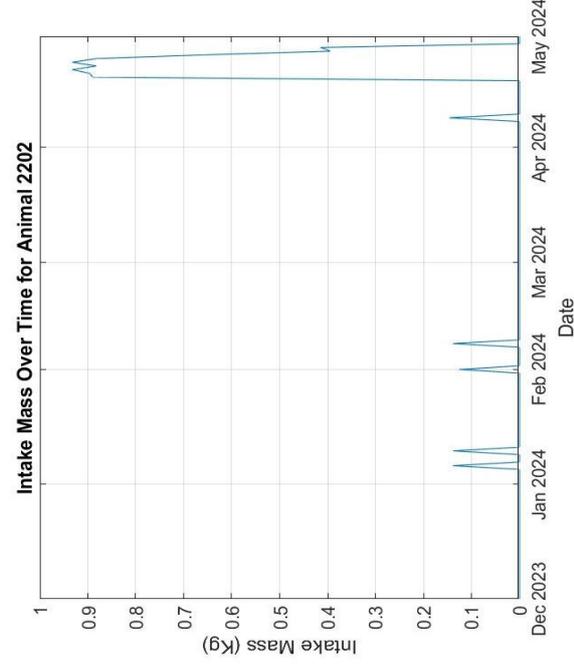
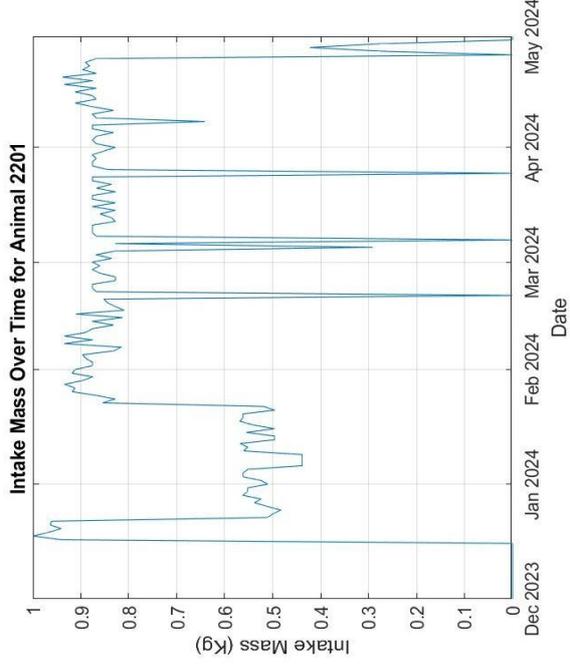
```
disp('- Script Complete -');
```

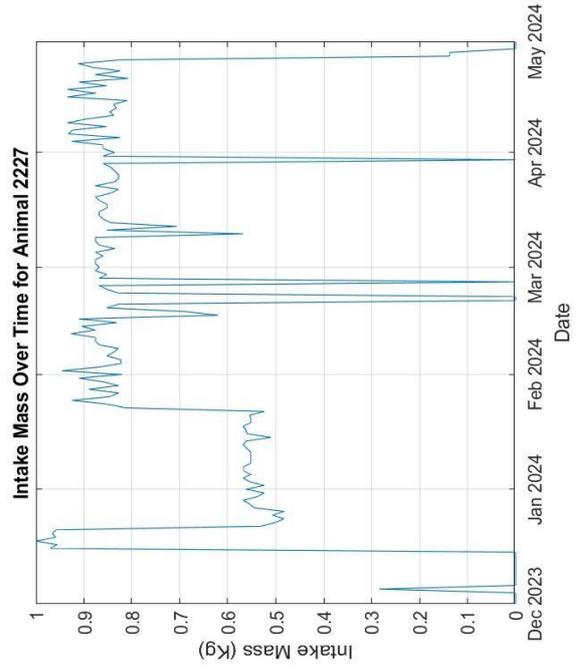
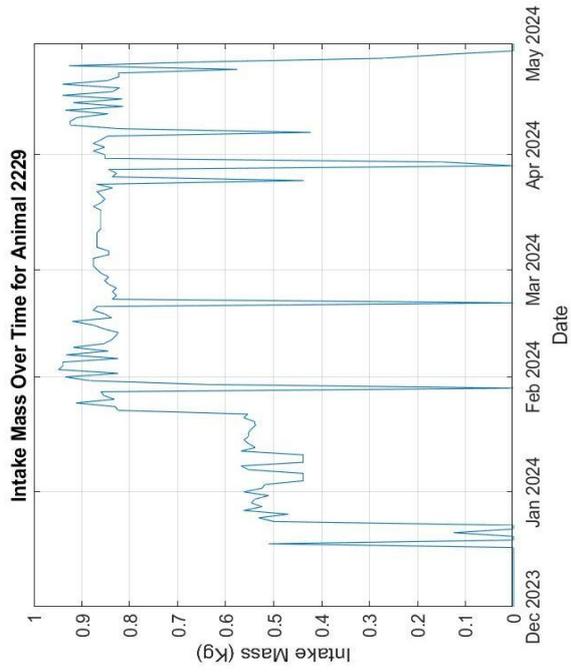
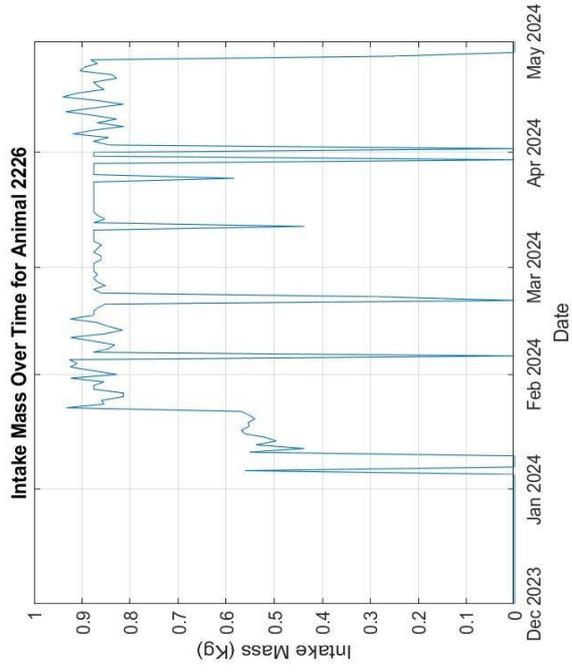
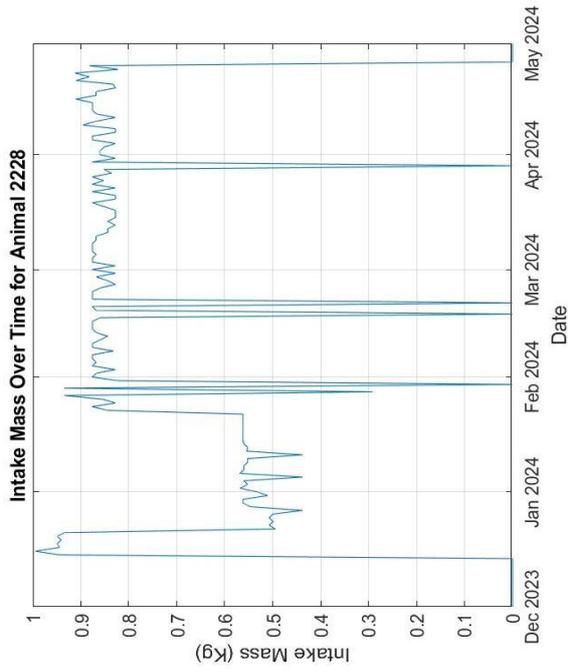
APPENDIX F: PROJECT TIMELINE

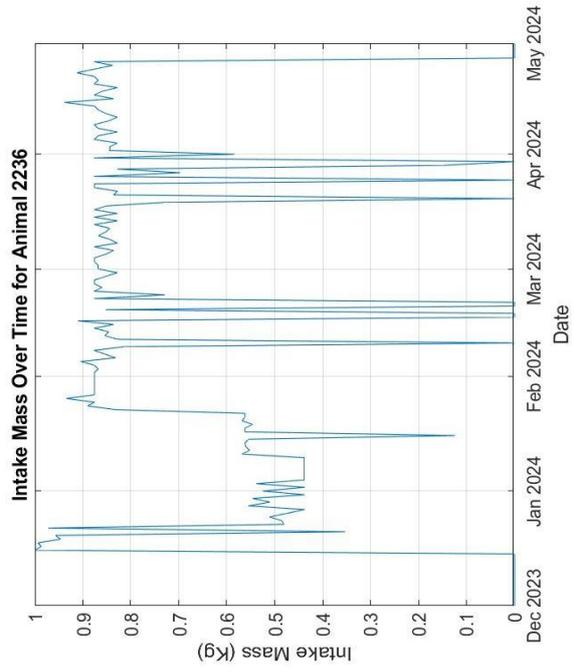
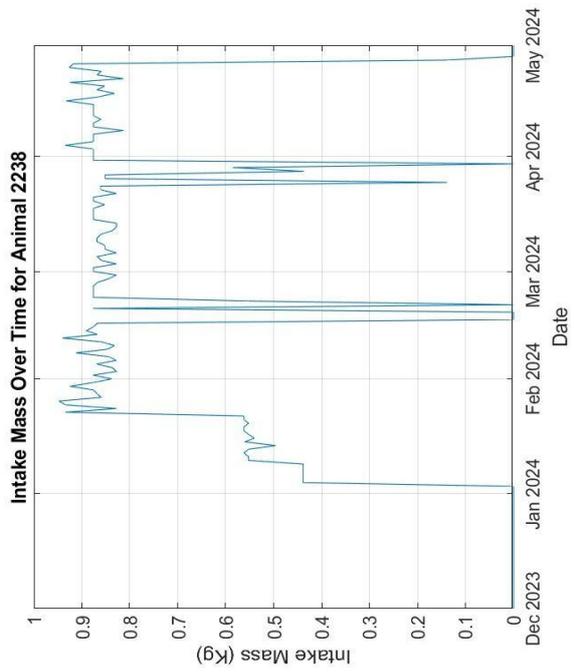
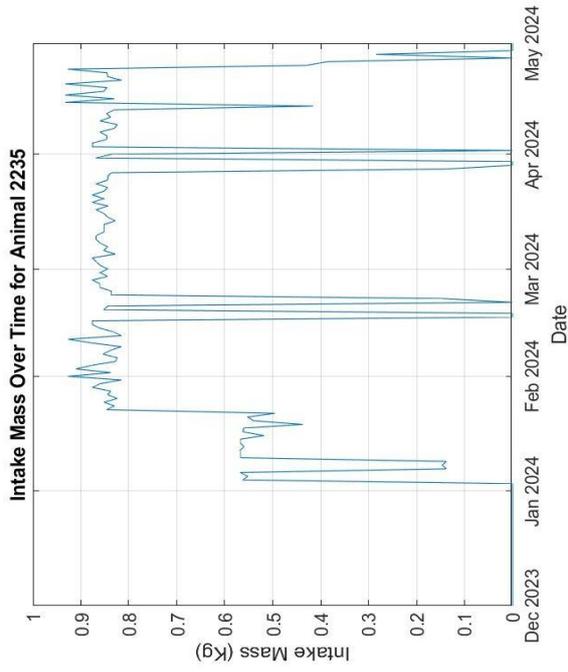
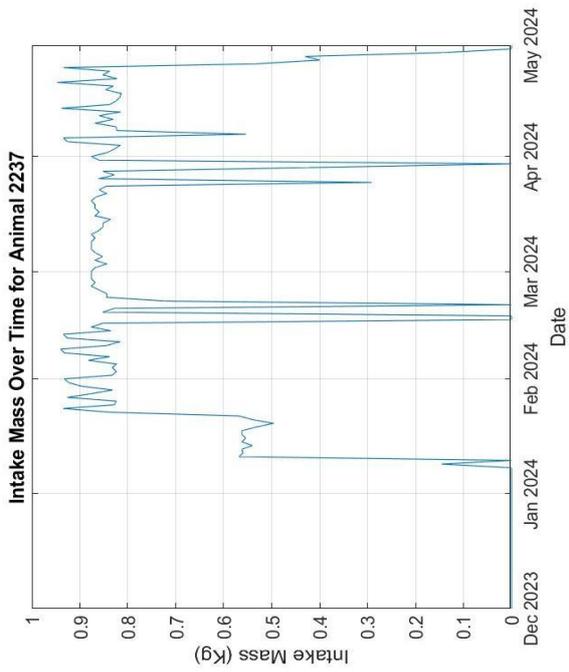
APPENDIX G: INDIVIDUAL ANIMAL FIGURES

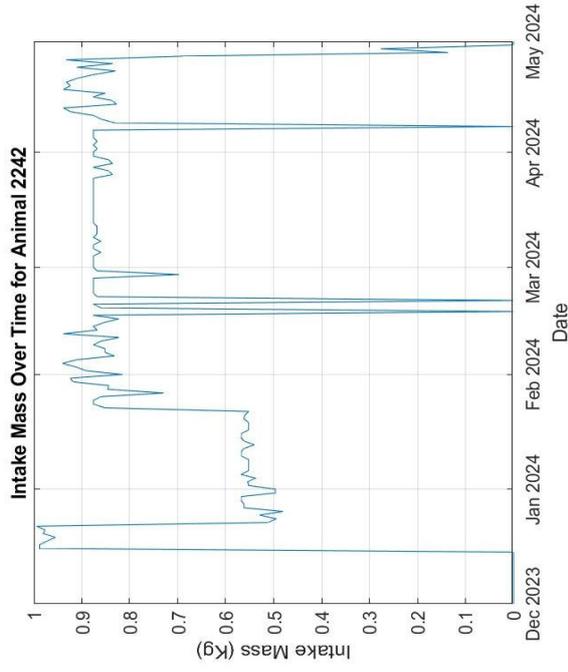
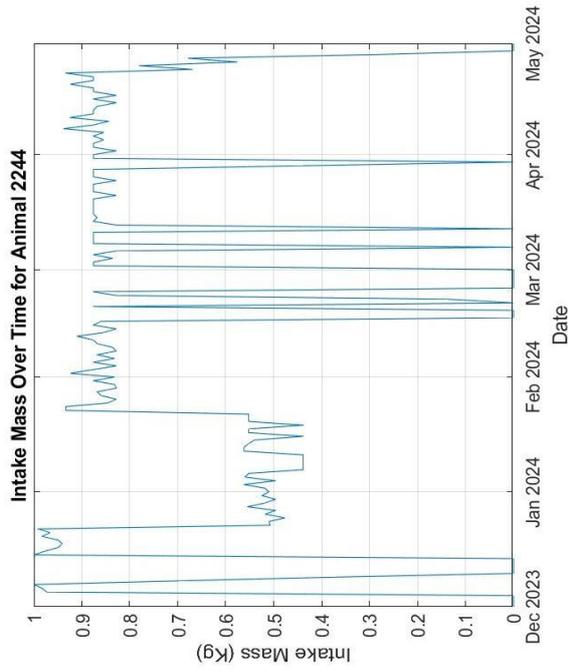
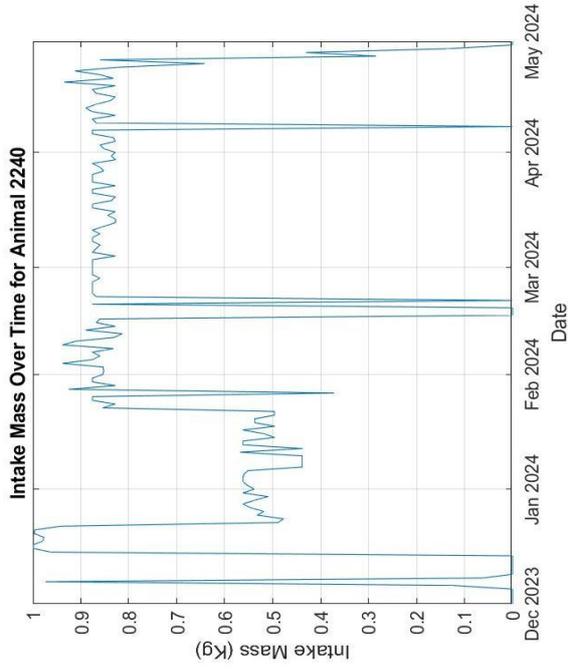
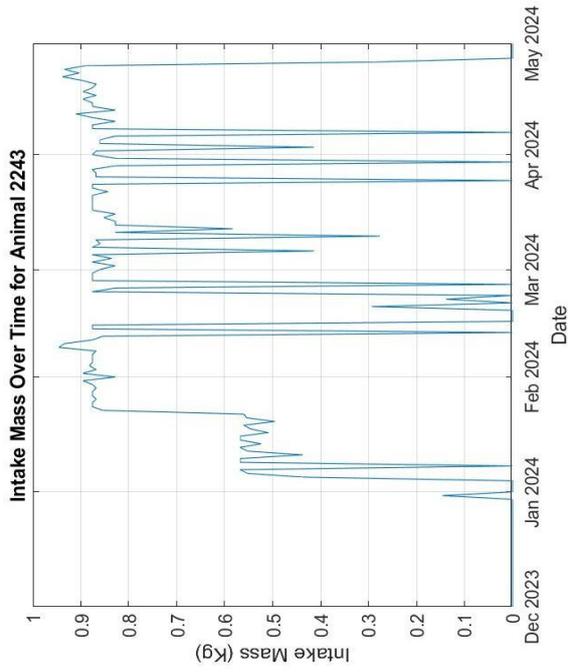
Individual Animal Feed Intakes



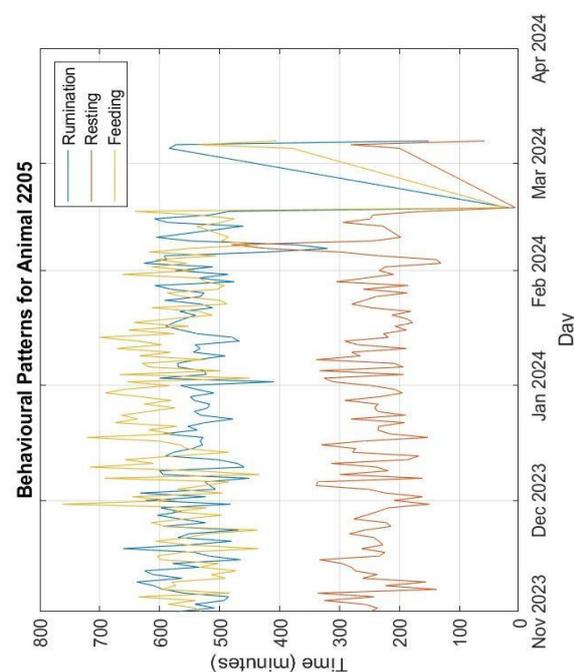
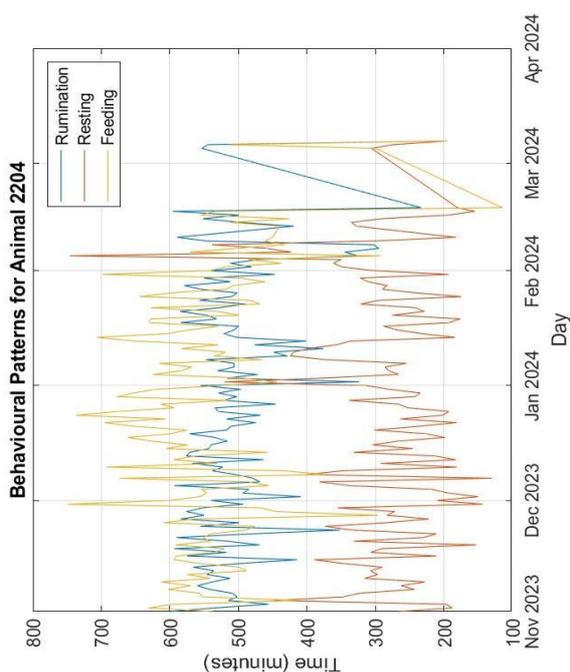
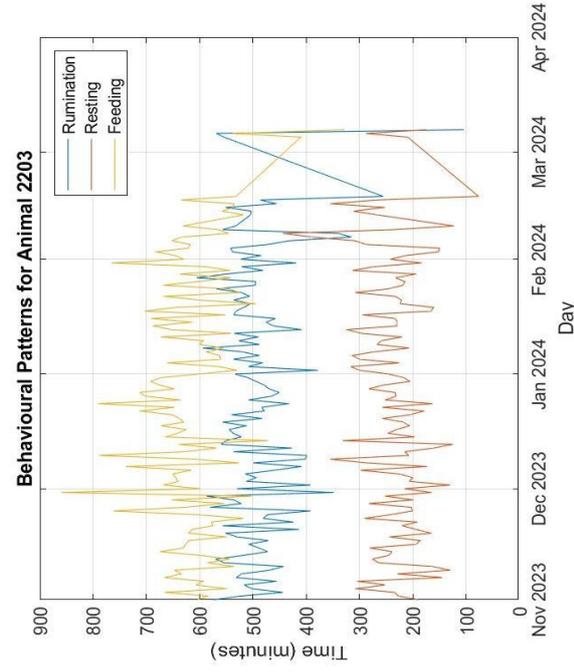
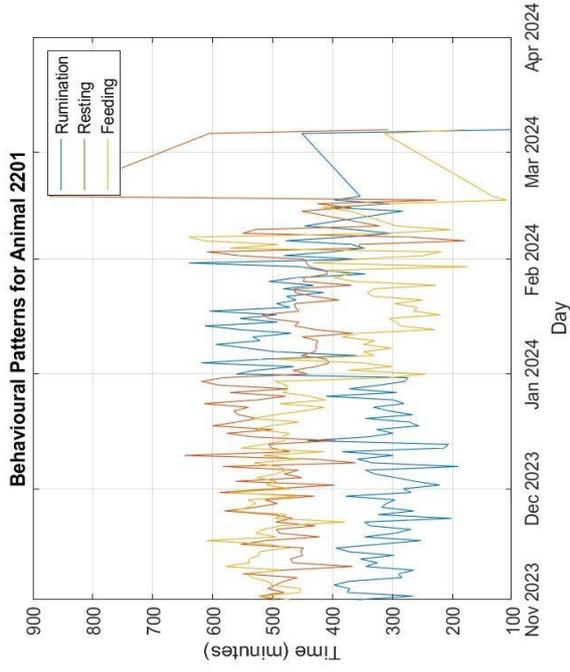


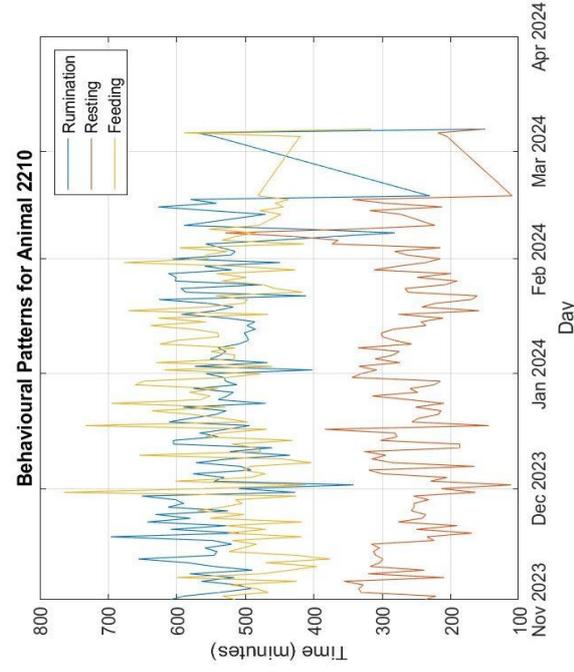
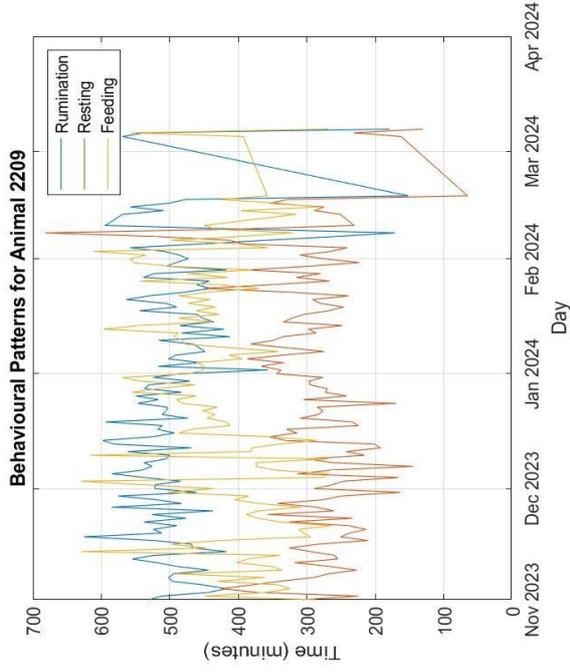
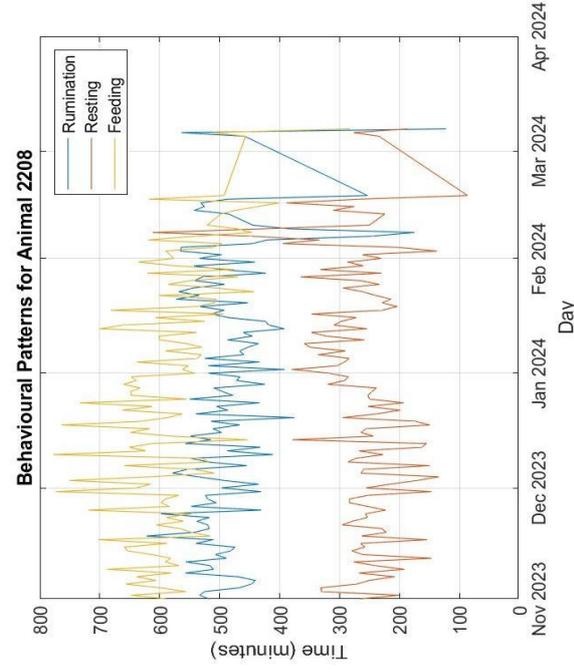
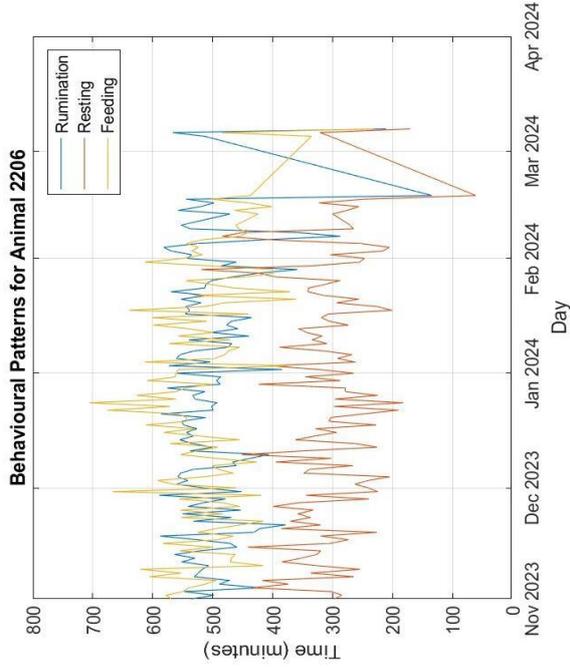


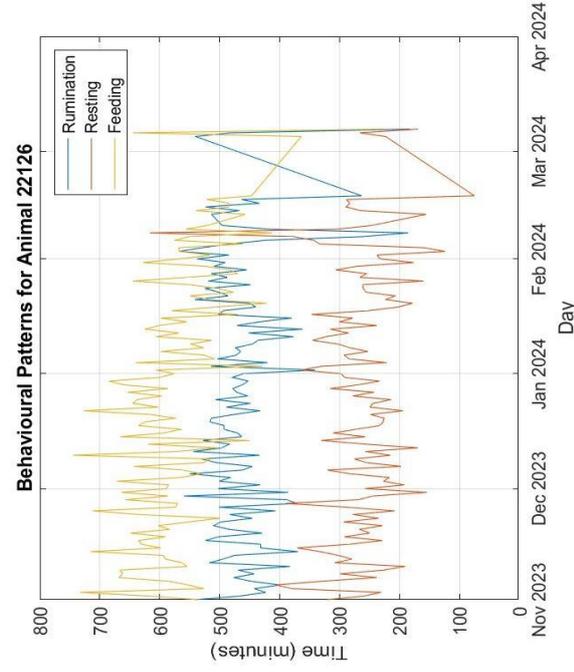
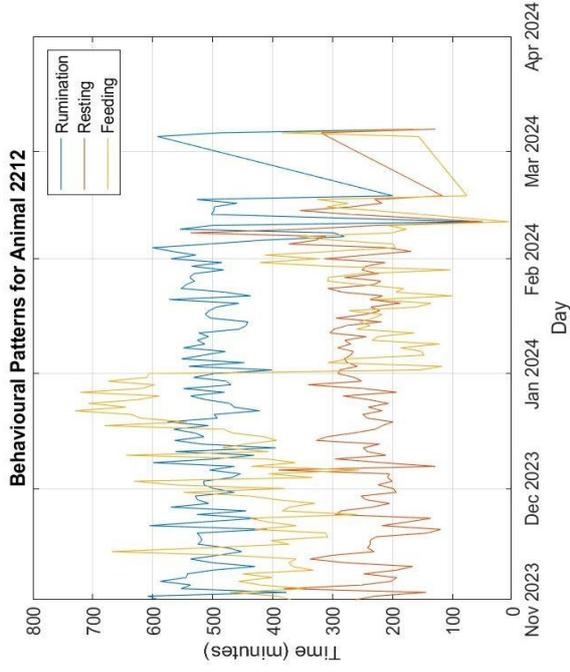
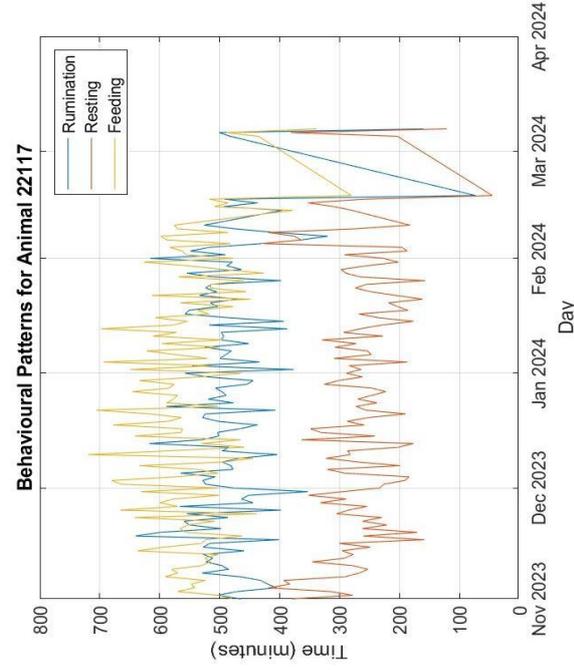
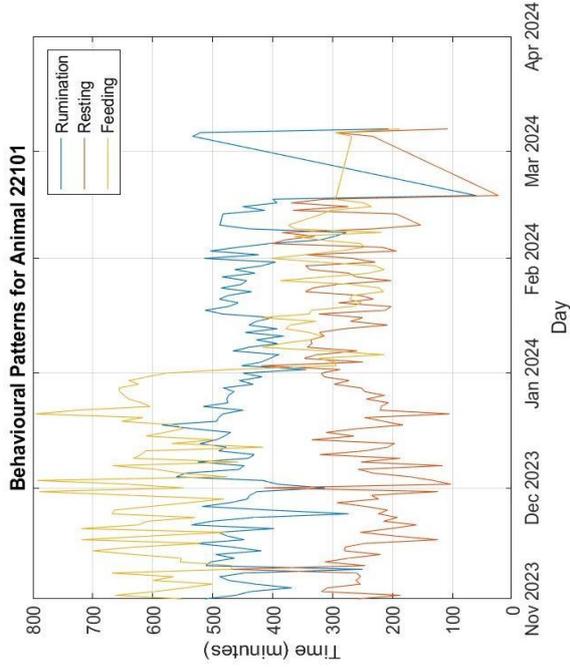


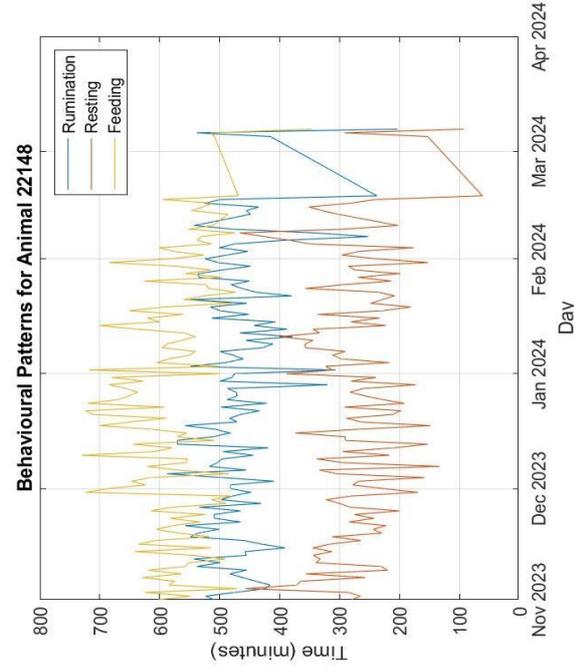
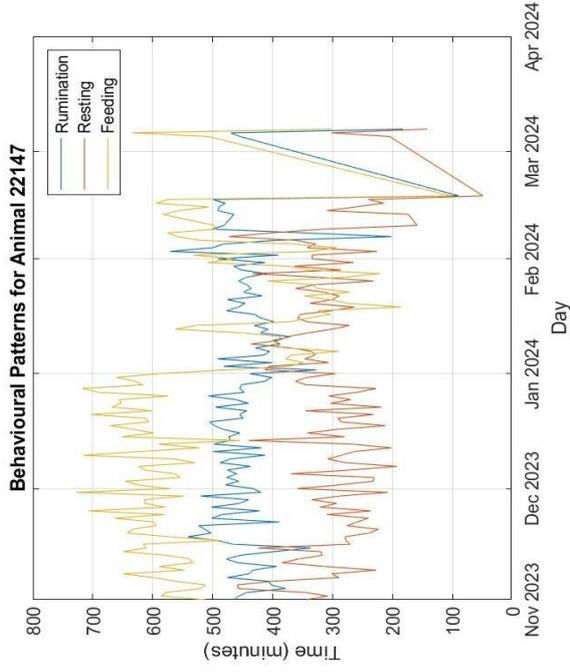
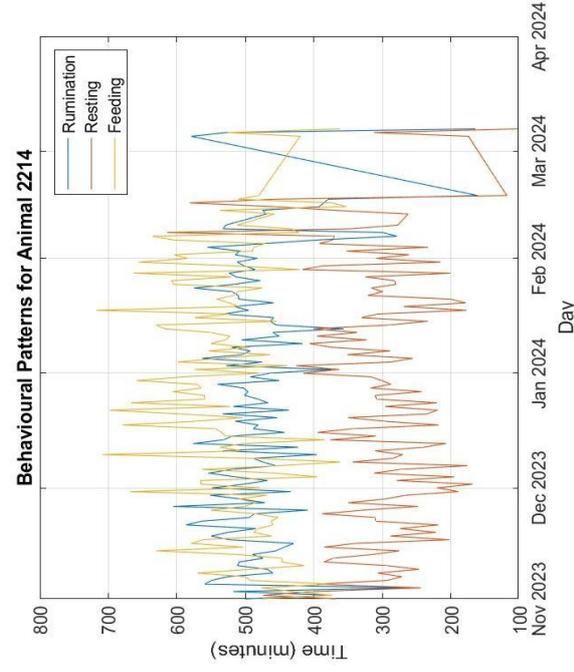
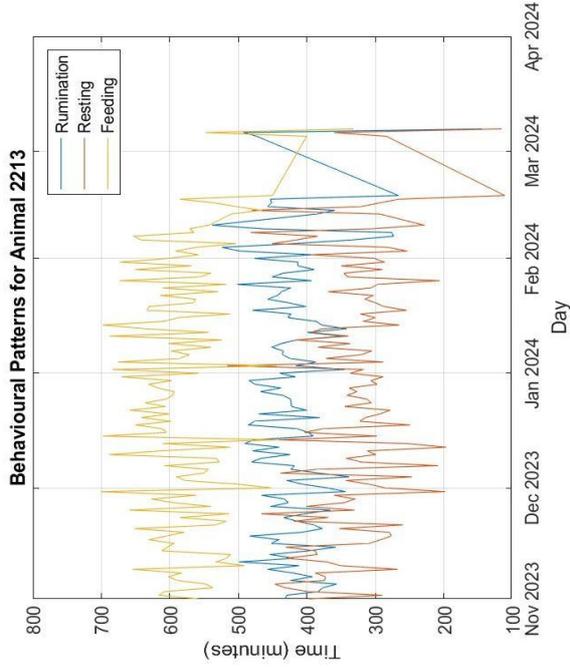


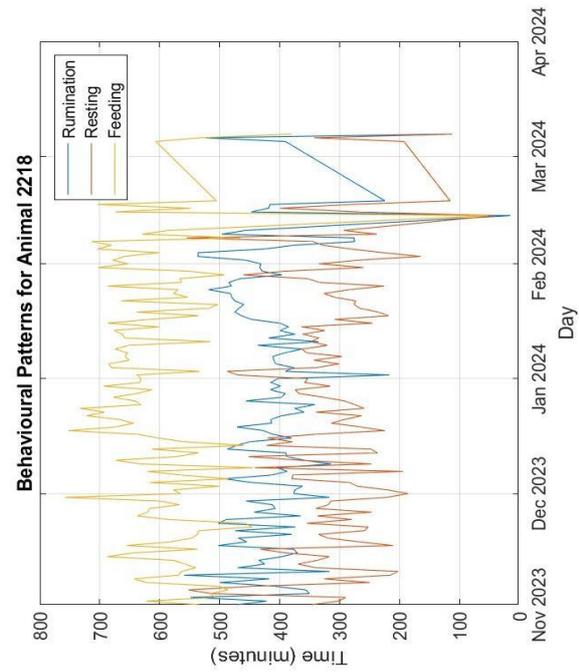
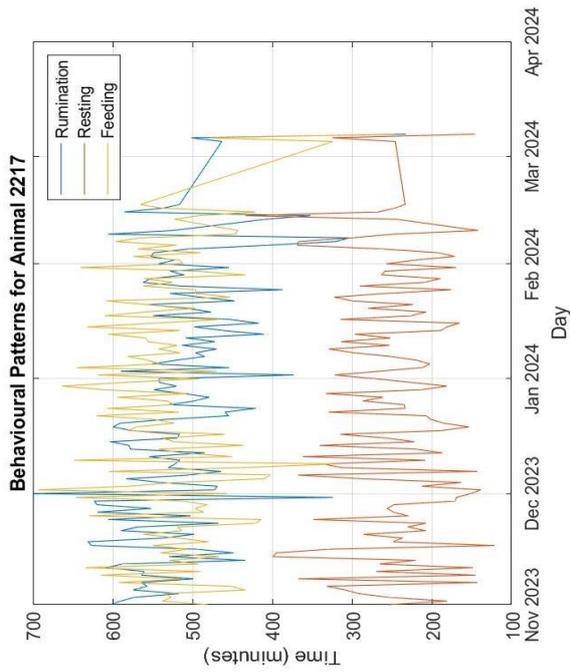
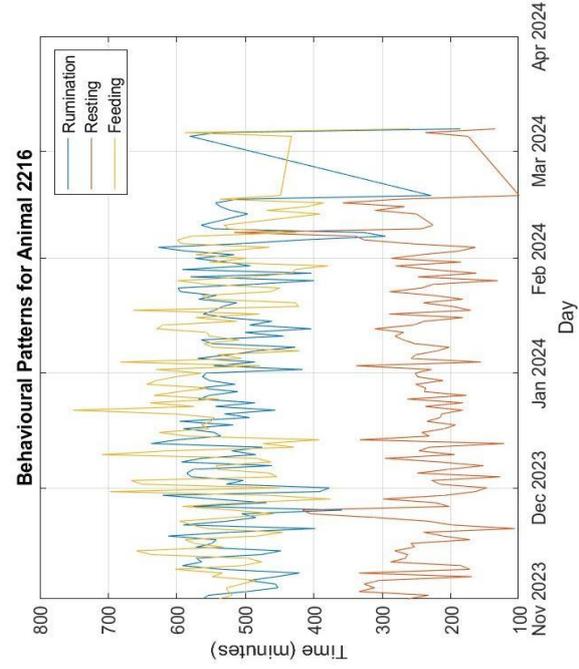
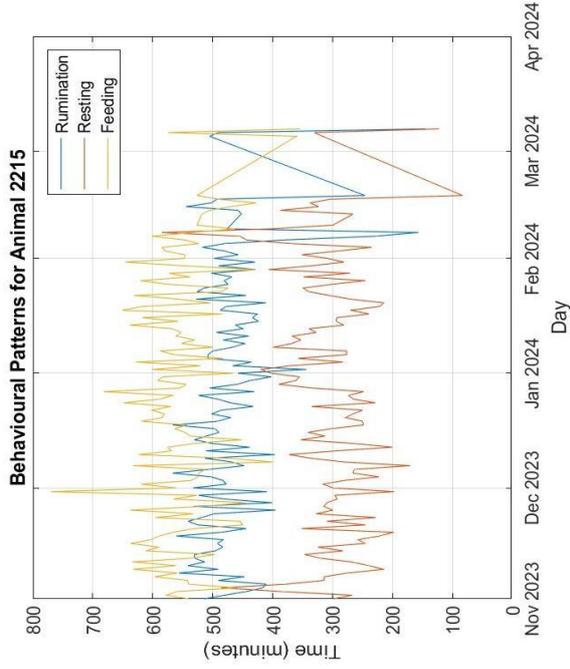
Individual Moomonitor Results



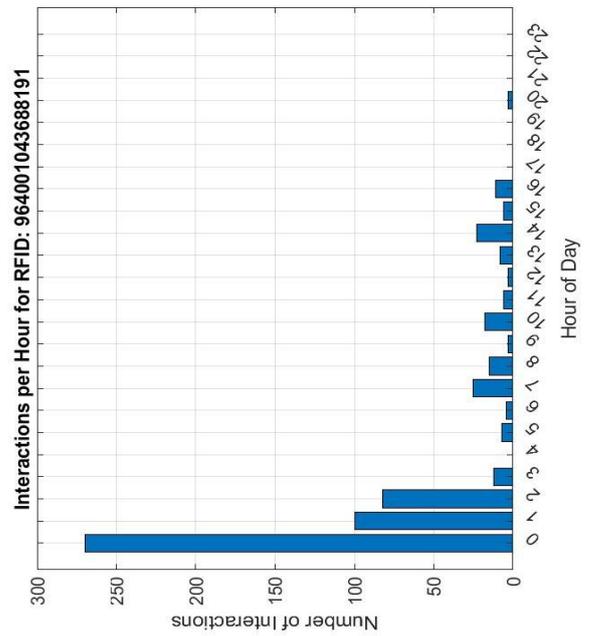
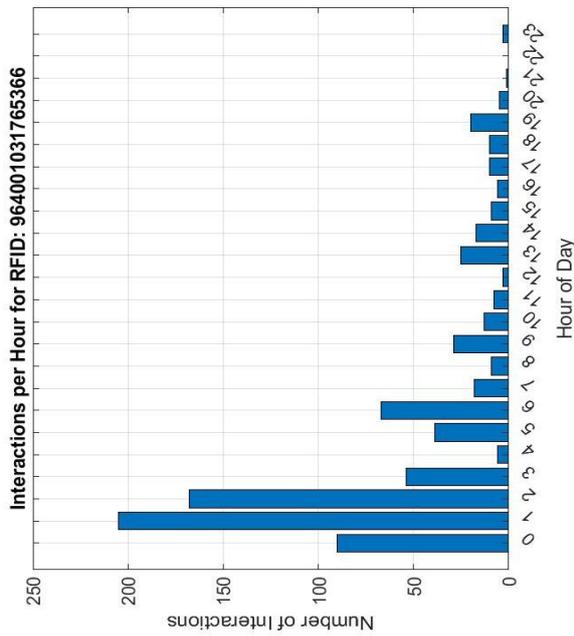
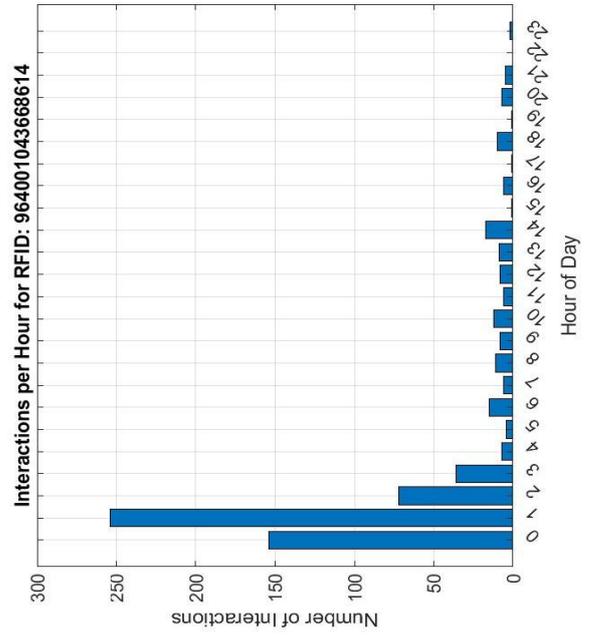
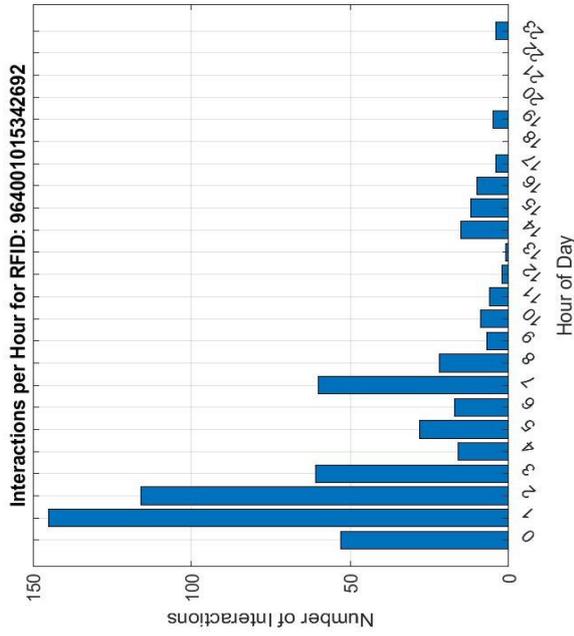


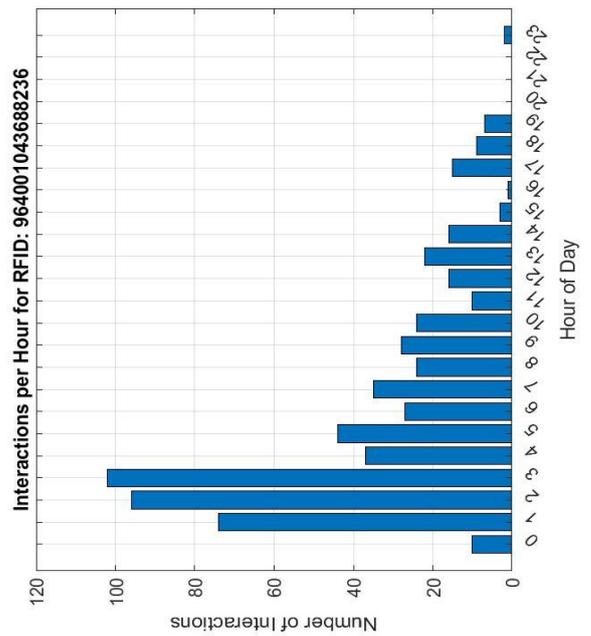
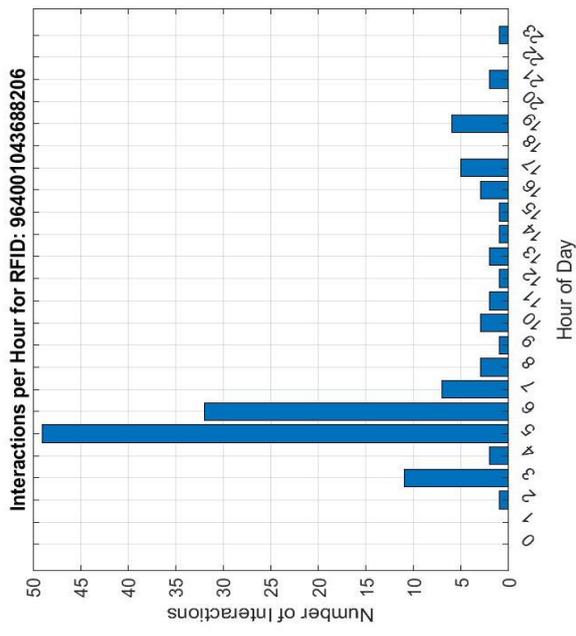
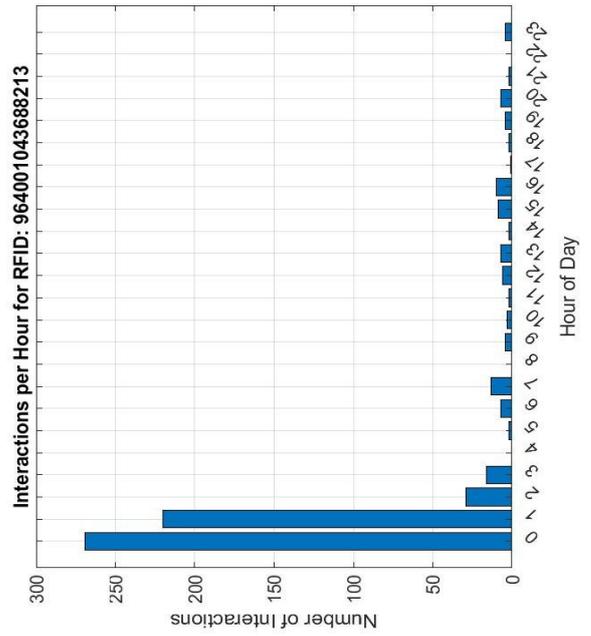
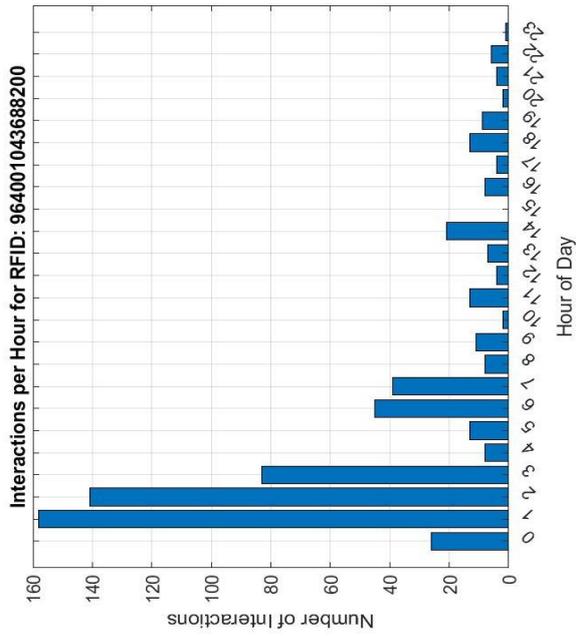


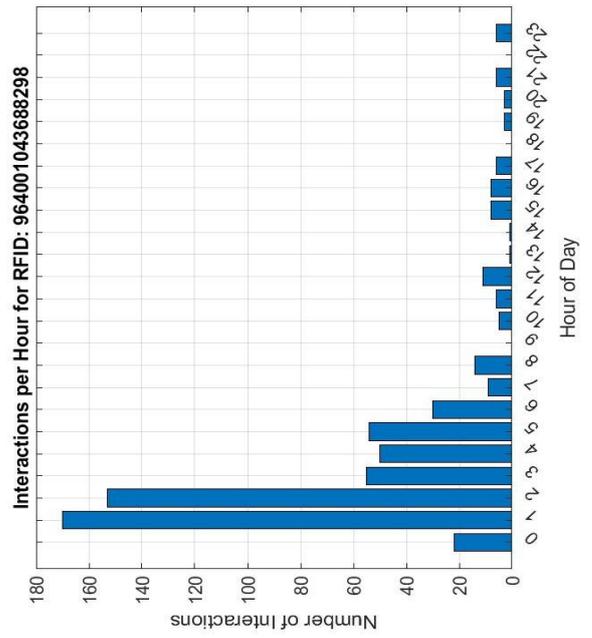
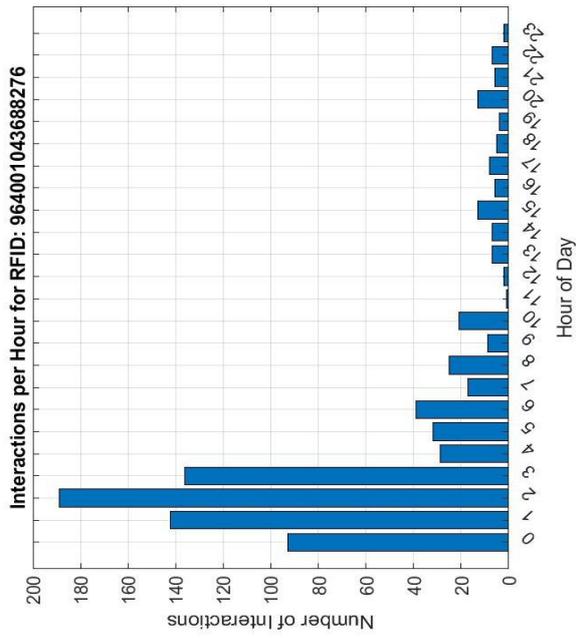
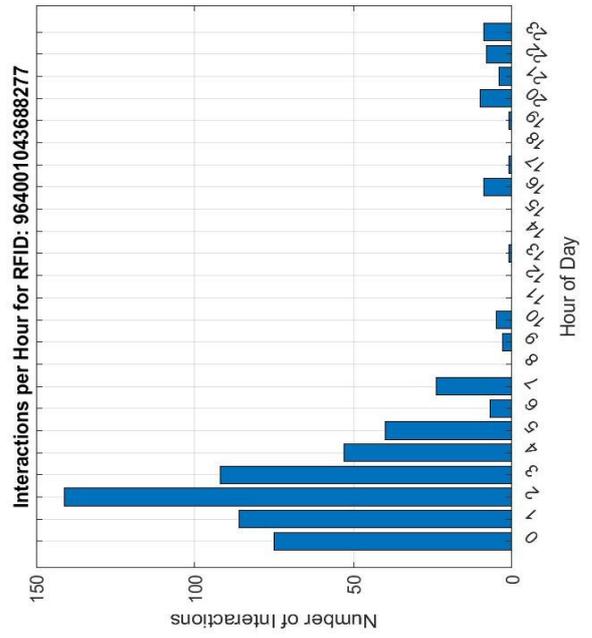
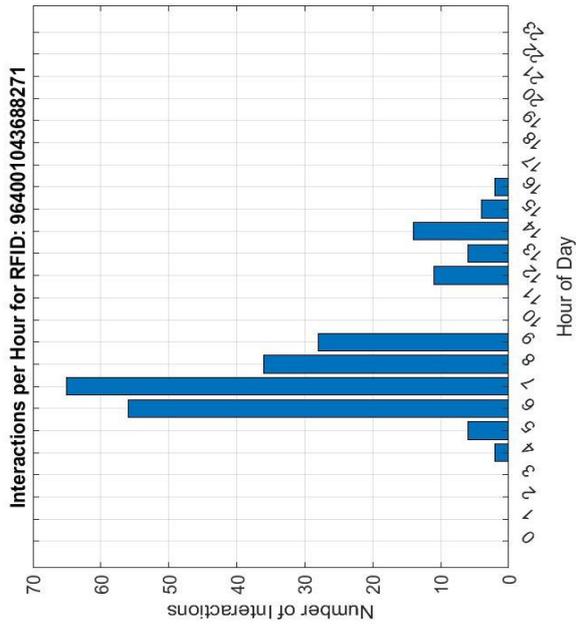


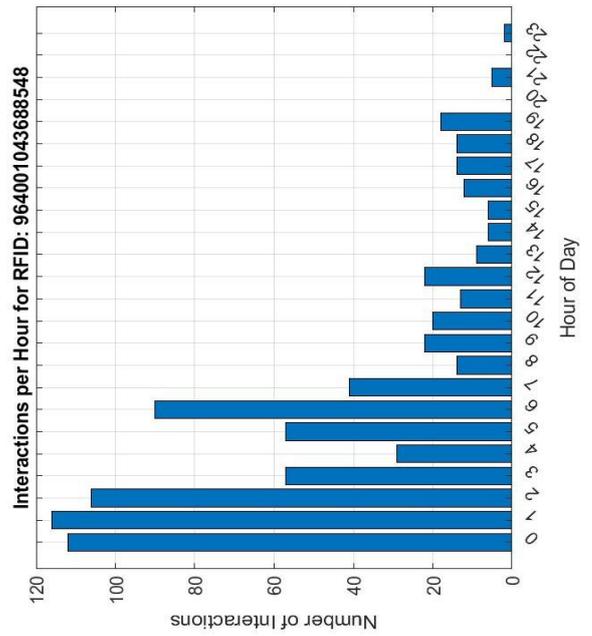
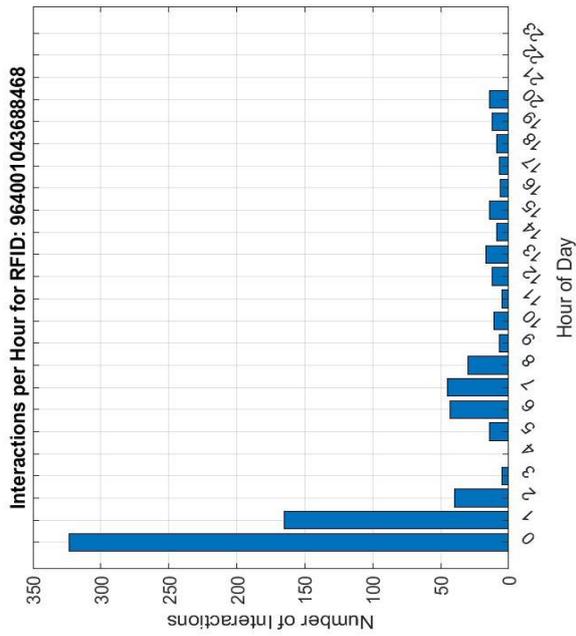
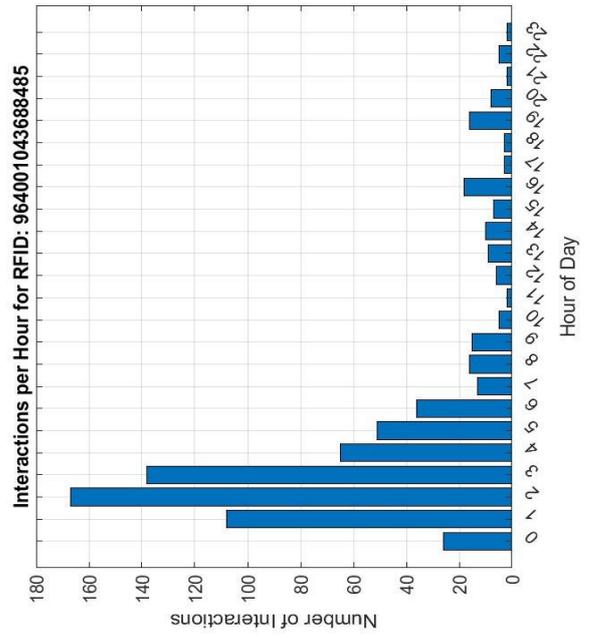
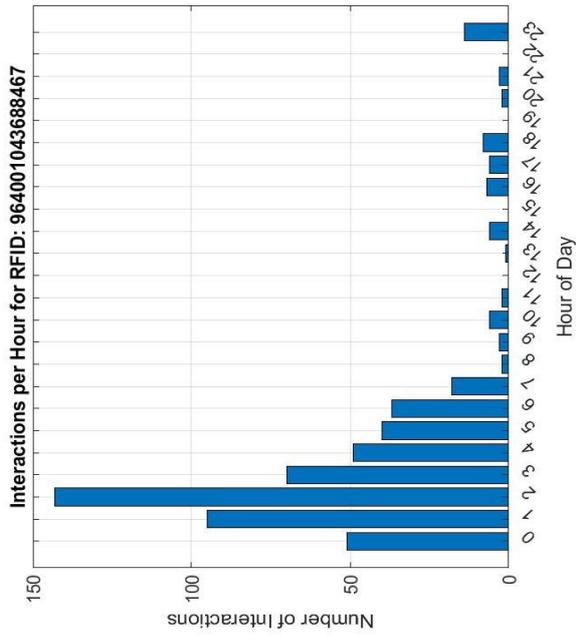


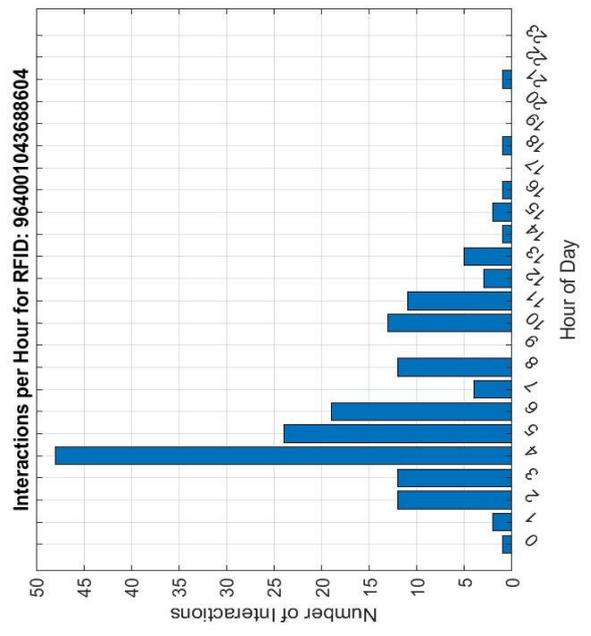
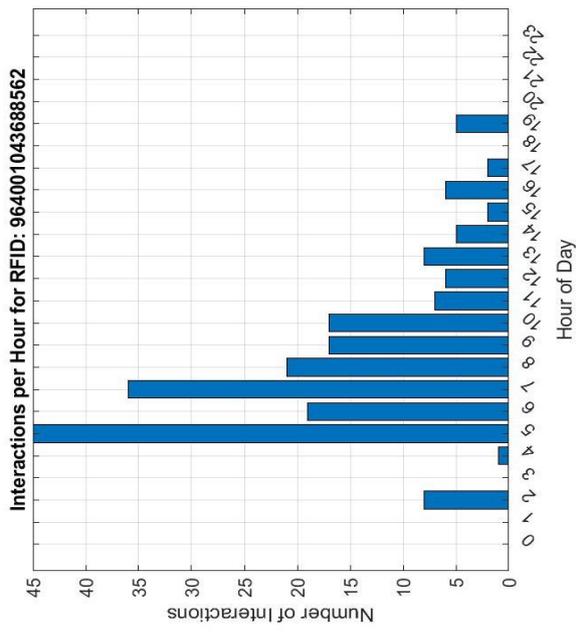
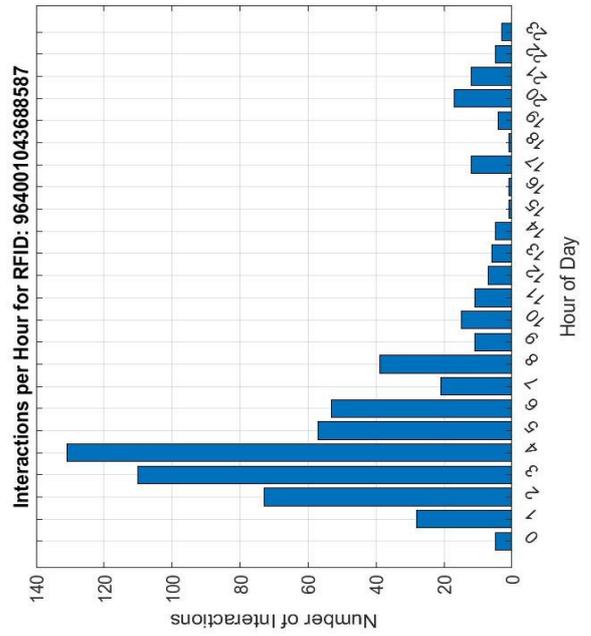
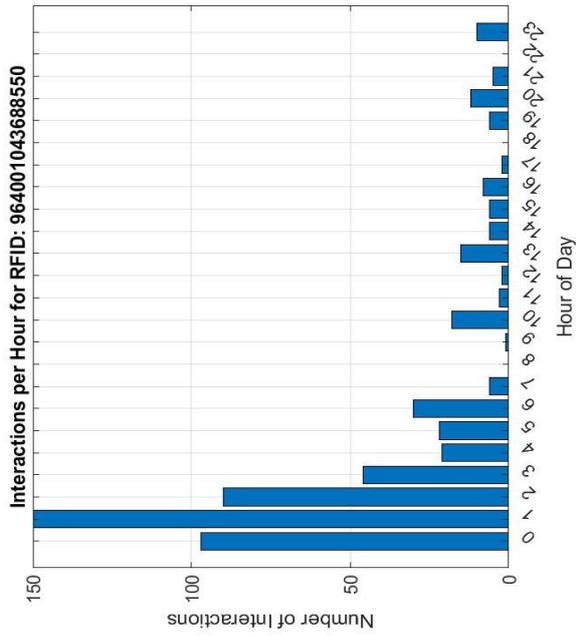
Daily Interaction Frequency











APPENDIX H: POST HOC TESTS

Post Hoc Comparisons - Hour of the Day

Comparison		Mean Difference	SE	df	t	Ptukey	Pholm	
Hour of the Day	Hour of the Day							
1	- 2	57.2466	19.437	72.0	2.9453	0.356	0.221	
	- 3	85.1096	23.001	72.0	3.7003	0.063	0.031	
	- 4	107.5479	22.941	72.0	4.6880	0.003	0.001	
	- 5	133.5205	22.141	72.0	6.0305	< .001	< .001	
	- 6	126.5616	21.456	72.0	5.8987	< .001	< .001	
	- 7	126.5616	21.374	72.0	5.9213	< .001	< .001	
	- 8	137.6164	20.930	72.0	6.5750	< .001	< .001	
	- 9	145.3973	20.529	72.0	7.0826	< .001	< .001	
	- 10	149.4658	20.378	72.0	7.3345	< .001	< .001	
	- 11	149.9178	20.037	72.0	7.4819	< .001	< .001	
	- 12	153.0137	20.242	72.0	7.5594	< .001	< .001	
	- 13	151.8082	20.201	72.0	7.5149	< .001	< .001	
	- 14	148.7123	19.686	72.0	7.5543	< .001	< .001	
	- 15	149.0137	19.932	72.0	7.4762	< .001	< .001	
	- 16	152.9315	20.161	72.0	7.5855	< .001	< .001	
	- 17	153.1644	20.307	72.0	7.5426	< .001	< .001	
	- 18	154.3836	20.181	72.0	7.6498	< .001	< .001	
	- 19	155.5068	20.227	72.0	7.6882	< .001	< .001	
	- 20	154.9726	20.127	72.0	7.6996	< .001	< .001	
	- 21	154.7123	20.065	72.0	7.7107	< .001	< .001	
	- 22	156.5342	20.176	72.0	7.7584	< .001	< .001	
	- 23	157.0959	20.215	72.0	7.7713	< .001	< .001	
	- 24	155.8493	20.069	72.0	7.7657	< .001	< .001	
	2	- 3	27.8630	7.986	72.0	3.4888	0.110	0.057
- 4		50.3014	9.286	72.0	5.4167	< .001	< .001	
- 5		76.2740	9.928	72.0	7.6825	< .001	< .001	
- 6		69.3151	9.789	72.0	7.0811	< .001	< .001	
- 7		69.3151	9.594	72.0	7.2249	< .001	< .001	
- 8		80.3699	8.655	72.0	9.2860	< .001	< .001	
- 9		88.1507	8.371	72.0	10.5299	< .001	< .001	
- 10		92.2192	8.264	72.0	11.1598	< .001	< .001	
- 11		92.6712	8.258	72.0	11.2221	< .001	< .001	
- 12		95.7671	8.044	72.0	11.9056	< .001	< .001	
- 13		94.5616	8.139	72.0	11.6181	< .001	< .001	
- 14		91.4658	7.888	72.0	11.5952	< .001	< .001	
- 15		91.7671	7.865	72.0	11.6671	< .001	< .001	
- 16		95.6849	7.945	72.0	12.0428	< .001	< .001	
- 17		95.9178	8.065	72.0	11.8933	< .001	< .001	
- 18		97.1370	8.088	72.0	12.0100	< .001	< .001	
- 19		98.2603	8.042	72.0	12.2191	< .001	< .001	
- 20		97.7260	8.090	72.0	12.0801	< .001	< .001	
- 21		97.4658	8.028	72.0	12.1406	< .001	< .001	
- 22		99.2877	8.082	72.0	12.2847	< .001	< .001	
- 23		99.8493	8.184	72.0	12.2004	< .001	< .001	
- 24		98.6027	8.072	72.0	12.2155	< .001	< .001	
3		- 4	22.4384	4.250	72.0	5.2796	< .001	< .001
		- 5	48.4110	6.126	72.0	7.9020	< .001	< .001

Post Hoc Comparisons - Hour of the Day

Comparison		Mean Difference	SE	df	t	Ptukey	Pholm
Hour of the Day	Hour of the Day						
	- 6	41.4521	6.738	72.0	6.1518	< .001	< .001
	- 7	41.4521	6.674	72.0	6.2105	< .001	< .001
	- 8	52.5068	6.210	72.0	8.4551	< .001	< .001
	- 9	60.2877	5.923	72.0	10.1787	< .001	< .001
	- 10	64.3562	5.970	72.0	10.7799	< .001	< .001
	- 11	64.8082	6.050	72.0	10.7120	< .001	< .001
	- 12	67.9041	5.923	72.0	11.4650	< .001	< .001
	- 13	66.6986	5.935	72.0	11.2381	< .001	< .001
	- 14	63.6027	6.055	72.0	10.5042	< .001	< .001
	- 15	63.9041	5.989	72.0	10.6711	< .001	< .001
	- 16	67.8219	5.933	72.0	11.4307	< .001	< .001
	- 17	68.0548	5.861	72.0	11.6116	< .001	< .001
	- 18	69.2740	5.985	72.0	11.5753	< .001	< .001
	- 19	70.3973	5.972	72.0	11.7878	< .001	< .001
	- 20	69.8630	6.032	72.0	11.5818	< .001	< .001
	- 21	69.6027	6.046	72.0	11.5119	< .001	< .001
	- 22	71.4247	5.949	72.0	12.0067	< .001	< .001
	- 23	71.9863	6.008	72.0	11.9825	< .001	< .001
	- 24	70.7397	6.024	72.0	11.7439	< .001	< .001
4	- 5	25.9726	3.571	72.0	7.2735	< .001	< .001
	- 6	19.0137	4.596	72.0	4.1366	0.017	0.008
	- 7	19.0137	4.802	72.0	3.9598	0.030	0.014
	- 8	30.0685	4.617	72.0	6.5123	< .001	< .001
	- 9	37.8493	4.392	72.0	8.6180	< .001	< .001
	- 10	41.9178	4.538	72.0	9.2380	< .001	< .001
	- 11	42.3699	4.704	72.0	9.0079	< .001	< .001
	- 12	45.4658	4.550	72.0	9.9915	< .001	< .001
	- 13	44.2603	4.547	72.0	9.7348	< .001	< .001
	- 14	41.1644	4.969	72.0	8.2845	< .001	< .001
	- 15	41.4658	4.781	72.0	8.6722	< .001	< .001
	- 16	45.3836	4.671	72.0	9.7164	< .001	< .001
	- 17	45.6164	4.557	72.0	10.0108	< .001	< .001
	- 18	46.8356	4.662	72.0	10.0468	< .001	< .001
	- 19	47.9589	4.678	72.0	10.2513	< .001	< .001
	- 20	47.4247	4.790	72.0	9.9015	< .001	< .001
	- 21	47.1644	4.734	72.0	9.9639	< .001	< .001
	- 22	48.9863	4.667	72.0	10.4972	< .001	< .001
	- 23	49.5479	4.644	72.0	10.6702	< .001	< .001
	- 24	48.3014	4.731	72.0	10.2090	< .001	< .001
5	- 6	-6.9589	2.935	72.0	-2.3713	0.759	0.857
	- 7	-6.9589	3.708	72.0	-1.8766	0.965	1.000
	- 8	4.0959	3.857	72.0	1.0620	1.000	1.000
	- 9	11.8767	3.444	72.0	3.4487	0.121	0.062
	- 10	15.9452	3.593	72.0	4.4378	0.006	0.003
	- 11	16.3973	3.690	72.0	4.4442	0.006	0.003
	- 12	19.4932	3.491	72.0	5.5835	< .001	< .001
	- 13	18.2877	3.451	72.0	5.2985	< .001	< .001
	- 14	15.1918	4.027	72.0	3.7729	0.051	0.025

Post Hoc Comparisons - Hour of the Day

Comparison		Mean Difference	SE	df	t	Ptukey	Pholm
Hour of the Day	Hour of the Day						
6	- 15	15.4932	3.850	72.0	4.0246	0.024	0.012
	- 16	19.4110	3.682	72.0	5.2720	< .001	< .001
	- 17	19.6438	3.503	72.0	5.6078	< .001	< .001
	- 18	20.8630	3.549	72.0	5.8778	< .001	< .001
	- 19	21.9863	3.608	72.0	6.0946	< .001	< .001
	- 20	21.4521	3.643	72.0	5.8892	< .001	< .001
	- 21	21.1918	3.555	72.0	5.9616	< .001	< .001
	- 22	23.0137	3.480	72.0	6.6126	< .001	< .001
	- 23	23.5753	3.512	72.0	6.7136	< .001	< .001
	- 24	22.3288	3.560	72.0	6.2726	< .001	< .001
	- 7	0.0000	2.871	72.0	0.0000	1.000	1.000
	- 8	11.0548	3.384	72.0	3.2668	0.186	0.103
	- 9	18.8356	3.483	72.0	5.4073	< .001	< .001
	- 10	22.9041	3.290	72.0	6.9609	< .001	< .001
	- 11	23.3562	3.450	72.0	6.7704	< .001	< .001
	- 12	26.4521	3.391	72.0	7.8013	< .001	< .001
	- 13	25.2466	3.213	72.0	7.8575	< .001	< .001
	- 14	22.1507	3.699	72.0	5.9876	< .001	< .001
	- 15	22.4521	3.650	72.0	6.1512	< .001	< .001
	- 16	26.3699	3.604	72.0	7.3161	< .001	< .001
	- 17	26.6027	3.522	72.0	7.5541	< .001	< .001
	- 18	27.8219	3.363	72.0	8.2724	< .001	< .001
	- 19	28.9452	3.488	72.0	8.2981	< .001	< .001
	- 20	28.4110	3.454	72.0	8.2266	< .001	< .001
- 21	28.1507	3.493	72.0	8.0583	< .001	< .001	
- 22	29.9726	3.414	72.0	8.7784	< .001	< .001	
- 23	30.5342	3.488	72.0	8.7540	< .001	< .001	
- 24	29.2877	3.409	72.0	8.5900	< .001	< .001	
7	- 8	11.0548	2.851	72.0	3.8780	0.038	0.019
	- 9	18.8356	3.026	72.0	6.2246	< .001	< .001
	- 10	22.9041	2.896	72.0	7.9088	< .001	< .001
	- 11	23.3562	3.191	72.0	7.3183	< .001	< .001
	- 12	26.4521	3.149	72.0	8.3996	< .001	< .001
	- 13	25.2466	2.950	72.0	8.5582	< .001	< .001
	- 14	22.1507	3.476	72.0	6.3726	< .001	< .001
	- 15	22.4521	3.391	72.0	6.6215	< .001	< .001
	- 16	26.3699	3.214	72.0	8.2052	< .001	< .001
	- 17	26.6027	3.244	72.0	8.2002	< .001	< .001
	- 18	27.8219	3.099	72.0	8.9773	< .001	< .001
	- 19	28.9452	3.135	72.0	9.2338	< .001	< .001
	- 20	28.4110	3.064	72.0	9.2736	< .001	< .001
	- 21	28.1507	3.175	72.0	8.8652	< .001	< .001
	- 22	29.9726	3.179	72.0	9.4268	< .001	< .001
	- 23	30.5342	3.204	72.0	9.5307	< .001	< .001
- 24	29.2877	3.284	72.0	8.9179	< .001	< .001	
8	- 9	7.7808	1.643	72.0	4.7350	0.002	0.001
	- 10	11.8493	1.762	72.0	6.7255	< .001	< .001
	- 11	12.3014	2.037	72.0	6.0375	< .001	< .001

Post Hoc Comparisons - Hour of the Day

Comparison		Mean Difference	SE	df	t	Ptukey	Pholm
Hour of the Day	Hour of the Day						
	- 12	15.3973	1.919	72.0	8.0257	< .001	< .001
	- 13	14.1918	1.889	72.0	7.5140	< .001	< .001
	- 14	11.0959	2.339	72.0	4.7433	0.002	0.001
	- 15	11.3973	2.053	72.0	5.5512	< .001	< .001
	- 16	15.3151	2.026	72.0	7.5611	< .001	< .001
	- 17	15.5479	1.993	72.0	7.8026	< .001	< .001
	- 18	16.7671	1.996	72.0	8.3993	< .001	< .001
	- 19	17.8904	2.012	72.0	8.8897	< .001	< .001
	- 20	17.3562	2.028	72.0	8.5571	< .001	< .001
	- 21	17.0959	2.083	72.0	8.2079	< .001	< .001
	- 22	18.9178	2.032	72.0	9.3097	< .001	< .001
	- 23	19.4795	1.965	72.0	9.9113	< .001	< .001
	- 24	18.2329	2.054	72.0	8.8751	< .001	< .001
9	- 10	4.0685	1.282	72.0	3.1728	0.229	0.124
	- 11	4.5205	1.304	72.0	3.4677	0.116	0.060
	- 12	7.6164	1.160	72.0	6.5665	< .001	< .001
	- 13	6.4110	1.218	72.0	5.2627	< .001	< .001
	- 14	3.3151	1.653	72.0	2.0060	0.934	1.000
	- 15	3.6164	1.404	72.0	2.5750	0.618	0.532
	- 16	7.5342	1.211	72.0	6.2231	< .001	< .001
	- 17	7.7671	1.259	72.0	6.1686	< .001	< .001
	- 18	8.9863	1.245	72.0	7.2188	< .001	< .001
	- 19	10.1096	1.222	72.0	8.2696	< .001	< .001
	- 20	9.5753	1.345	72.0	7.1201	< .001	< .001
	- 21	9.3151	1.299	72.0	7.1698	< .001	< .001
	- 22	11.1370	1.238	72.0	8.9987	< .001	< .001
	- 23	11.6986	1.226	72.0	9.5426	< .001	< .001
	- 24	10.4521	1.349	72.0	7.7467	< .001	< .001
10	- 11	0.4521	1.171	72.0	0.3860	1.000	1.000
	- 12	3.5479	1.010	72.0	3.5120	0.103	0.054
	- 13	2.3425	1.064	72.0	2.2023	0.856	1.000
	- 14	-0.7534	1.421	72.0	-0.5303	1.000	1.000
	- 15	-0.4521	1.192	72.0	-0.3793	1.000	1.000
	- 16	3.4658	1.156	72.0	2.9980	0.324	0.198
	- 17	3.6986	1.188	72.0	3.1126	0.259	0.146
	- 18	4.9178	1.140	72.0	4.3123	0.010	0.004
	- 19	6.0411	1.058	72.0	5.7102	< .001	< .001
	- 20	5.5068	1.109	72.0	4.9671	0.001	< .001
	- 21	5.2466	1.135	72.0	4.6223	0.003	0.001
	- 22	7.0685	1.079	72.0	6.5491	< .001	< .001
	- 23	7.6301	1.084	72.0	7.0383	< .001	< .001
	- 24	6.3836	1.118	72.0	5.7073	< .001	< .001
11	- 12	3.0959	0.973	72.0	3.1811	0.225	0.123
	- 13	1.8904	0.994	72.0	1.9011	0.961	1.000
	- 14	-1.2055	1.130	72.0	-1.0672	1.000	1.000
	- 15	-0.9041	1.115	72.0	-0.8107	1.000	1.000
	- 16	3.0137	1.042	72.0	2.8932	0.390	0.242
	- 17	3.2466	1.104	72.0	2.9418	0.359	0.221

Post Hoc Comparisons - Hour of the Day

Comparison		Mean Difference	SE	df	t	Ptukey	Pholm
Hour of the Day	Hour of the Day						
12	- 18	4.4658	0.946	72.0	4.7194	0.002	0.001
	- 19	5.5890	0.983	72.0	5.6852	< .001	< .001
	- 20	5.0548	0.981	72.0	5.1539	< .001	< .001
	- 21	4.7945	1.033	72.0	4.6400	0.003	0.001
	- 22	6.6164	0.983	72.0	6.7332	< .001	< .001
	- 23	7.1781	0.992	72.0	7.2357	< .001	< .001
	- 24	5.9315	0.940	72.0	6.3125	< .001	< .001
	- 13	-1.2055	0.804	72.0	-1.4993	0.998	1.000
	- 14	-4.3014	1.166	72.0	-3.6901	0.065	0.032
	- 15	-4.0000	0.902	72.0	-4.4358	0.007	0.003
	- 16	-0.0822	0.831	72.0	-0.0989	1.000	1.000
	13	- 17	0.1507	0.792	72.0	0.1902	1.000
- 18		1.3699	0.788	72.0	1.7375	0.985	1.000
- 19		2.4932	0.691	72.0	3.6105	0.080	0.040
- 20		1.9589	0.870	72.0	2.2514	0.830	1.000
- 21		1.6986	0.842	72.0	2.0171	0.930	1.000
- 22		3.5205	0.649	72.0	5.4217	< .001	< .001
- 23		4.0822	0.699	72.0	5.8407	< .001	< .001
- 24		2.8356	0.750	72.0	3.7824	0.050	0.024
- 14		-3.0959	1.274	72.0	-2.4310	0.720	0.755
- 15		-2.7945	1.043	72.0	-2.6783	0.542	0.431
- 16		1.1233	0.841	72.0	1.3356	1.000	1.000
14		- 17	1.3562	0.964	72.0	1.4073	0.999
	- 18	2.5753	0.789	72.0	3.2631	0.188	0.103
	- 19	3.6986	0.822	72.0	4.4970	0.005	0.002
	- 20	3.1644	0.900	72.0	3.5149	0.103	0.054
	- 21	2.9041	0.999	72.0	2.9062	0.382	0.238
	- 22	4.7260	0.773	72.0	6.1101	< .001	< .001
	- 23	5.2877	0.877	72.0	6.0260	< .001	< .001
	- 24	4.0411	0.929	72.0	4.3505	0.009	0.004
	- 15	0.3014	1.286	72.0	0.2343	1.000	1.000
	- 16	4.2192	1.285	72.0	3.2842	0.179	0.100
	- 17	4.4521	1.330	72.0	3.3480	0.154	0.083
	15	- 18	5.6712	1.241	72.0	4.5689	0.004
- 19		6.7945	1.274	72.0	5.3341	< .001	< .001
- 20		6.2603	1.216	72.0	5.1502	< .001	< .001
- 21		6.0000	1.224	72.0	4.9040	0.001	< .001
- 22		7.8219	1.192	72.0	6.5626	< .001	< .001
- 23		8.3836	1.292	72.0	6.4875	< .001	< .001
- 24		7.1370	1.205	72.0	5.9241	< .001	< .001
- 16		3.9178	1.060	72.0	3.6967	0.063	0.031
- 17		4.1507	1.085	72.0	3.8256	0.044	0.022
- 18		5.3699	0.996	72.0	5.3930	< .001	< .001
- 19		6.4932	0.934	72.0	6.9541	< .001	< .001
- 20		5.9589	1.008	72.0	5.9092	< .001	< .001
- 21	5.6986	0.998	72.0	5.7120	< .001	< .001	
- 22	7.5205	0.937	72.0	8.0283	< .001	< .001	
- 23	8.0822	0.963	72.0	8.3899	< .001	< .001	

Post Hoc Comparisons - Hour of the Day

Comparison		Mean Difference	SE	df	t	Ptukey	Pholm
Hour of the Day	Hour of the Day						
16	- 24	6.8356	0.971	72.0	7.0380	< .001	< .001
	- 17	0.2329	0.862	72.0	0.2702	1.000	1.000
	- 18	1.4521	0.781	72.0	1.8592	0.969	1.000
	- 19	2.5753	0.803	72.0	3.2059	0.213	0.117
	- 20	2.0411	0.790	72.0	2.5834	0.612	0.532
	- 21	1.7808	0.834	72.0	2.1357	0.886	1.000
	- 22	3.6027	0.761	72.0	4.7330	0.002	0.001
17	- 23	4.1644	0.725	72.0	5.7447	< .001	< .001
	- 24	2.9178	0.816	72.0	3.5779	0.087	0.044
	- 18	1.2192	0.879	72.0	1.3868	0.999	1.000
	- 19	2.3425	0.755	72.0	3.1034	0.264	0.148
	- 20	1.8082	0.845	72.0	2.1387	0.885	1.000
	- 21	1.5479	0.854	72.0	1.8119	0.976	1.000
	- 22	3.3699	0.667	72.0	5.0559	< .001	< .001
18	- 23	3.9315	0.672	72.0	5.8466	< .001	< .001
	- 24	2.6849	0.782	72.0	3.4326	0.126	0.065
	- 19	1.1233	0.636	72.0	1.7671	0.982	1.000
	- 20	0.5890	0.695	72.0	0.8477	1.000	1.000
	- 21	0.3288	0.832	72.0	0.3949	1.000	1.000
	- 22	2.1507	0.666	72.0	3.2279	0.203	0.111
	- 23	2.7123	0.714	72.0	3.7963	0.048	0.024
19	- 24	1.4658	0.688	72.0	2.1312	0.888	1.000
	- 20	-0.5342	0.622	72.0	-0.8583	1.000	1.000
	- 21	-0.7945	0.739	72.0	-1.0756	1.000	1.000
	- 22	1.0274	0.628	72.0	1.6371	0.993	1.000
	- 23	1.5890	0.605	72.0	2.6280	0.579	0.483
20	- 24	0.3425	0.622	72.0	0.5510	1.000	1.000
	- 21	-0.2603	0.748	72.0	-0.3481	1.000	1.000
	- 22	1.5616	0.701	72.0	2.2281	0.843	1.000
	- 23	2.1233	0.713	72.0	2.9780	0.336	0.205
21	- 24	0.8767	0.737	72.0	1.1902	1.000	1.000
	- 22	1.8219	0.561	72.0	3.2491	0.194	0.106
	- 23	2.3836	0.628	72.0	3.7970	0.048	0.024
22	- 24	1.1370	0.666	72.0	1.7082	0.988	1.000
	- 23	0.5616	0.509	72.0	1.1041	1.000	1.000
	- 24	-0.6849	0.537	72.0	-1.2763	1.000	1.000
23	- 24	-1.2466	0.563	72.0	-2.2144	0.850	1.000