Final report

Proof of concept for international cold chain monitoring and automated reporting

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ABSTRACT

Australian red meat processors and Importers are critical in influencing temperature control through the supply chain. The sharing of data between these two parties can be particularly influential in the end outcome for the product. This research is to qualify the requirement to track and monitor the temperature and location of product in red meat cold chains and the benefits of sharing that data with other participants in the supply chain.

The Escavox system was used to track 1000 cartons of red meat to 22 countries and the shelf life data analysed to identify crucial variability points within the cold supply chain.

Results showed significant variability in temperature control and shelf life outcomes for all export sea and air freight routes and that long shelf life can be achieved but is not guaranteed. Tracking the temperature and location of product in red meat cold chains is fundamental to identifying and fixing issues in the supply chain.

Benefits shown were increased sales volumes (7x), Reduction in freight costs saving $3.82 / Kg, maintained Australian competitive advantage, more beneficial market access protocols supported and where data was shared with importers, significant increases in shelf life.

Executive summary

Background

Australian red meat processors and Importers are critical in influencing temperature control through the supply chain. The sharing of data between these two parties can be particularly influential in the end outcome for the product. This research is to qualify the requirement to track and monitor the temperature and location of product in red meat cold chains and the benefits of sharing that data with other participants in the supply chain.

Red Meat export supply chains are inherently complicated, fragmented and diverse. It is well known that temperature control can often suffer due to these factors. It is difficult to know where these failures occur, for how long, who is responsible and the impact this has on the product.

In order to maximise shelf life and brand reputation to importers of Australian export meat, ideal temperatures of -0.5ºC should be maintained, and the impact of higher temperatures measured in days of shelf life lost rather than days in journey should be well understood in order to assess risks and potential product impact.

Objectives

- Track actual cartons of Australian red meat exports to various countries using assorted freight methods to identify crucial variability points within the cold supply chain from abattoir to arrival at importing country.
- Calculate the impact on the shelf life of each carton tracked in the study and provide a real-use case of MLA shelf life algorithm
- Investigate the variability between shelf life outcomes from air and sea freight and test the hypothesis that air freight delivers a longer shelf life for the consumer.
- Identify any temperature incursions in the cold supply chain to provide data for improvement or changes in practice to improve shelf life and quality of red meat.

Methodology

- 1000 cartons of red meat were tracked by air or sea from 20 exporters through unique supply chain journeys to 22 different countries.
- MLA's shelf life prediction model was integrated into the Escavox system so time, temperature, location, leg and shelf life data of export supply chains could be visualised and analysed.
- Each track was analysed for average temperature, duration of the journey, shelf life lost in the journey, shelf life remaining on arrival if held at the recommended -0.5C and average shelf life lost per day. An analysis of some tracks using varied starting microbiological count was also conducted.

Results/key findings

- Auto generated tracking data for one of the project participants proved sea freight suitability for US shipments resulted in 7x higher volume sales, reduced freight costs of $3.82/kg and enhanced brand reputation when compared to air freight.

- Storage temperature has significantly more impact on shelf life than starting microbiological count.
- Sea freight has better temperature control than air freight, resulting in a reduced rate of shelf life loss.
- There is significant variability in temperature control and shelf life outcomes in all export routes. There are no consistently 'good' or consistently 'bad' routes or shipment modes.
- Identifying the leg where problems occur allows the implementation of changes that can extend shelf life.
- Long shelf life can be achieved but is not guaranteed. Tracking the temperature and location of product in red meat cold chains is fundamental to identifying and fixing issues in the supply chain. Ideally, all routes should be tracked, but at a minimum, problem routes should be audited.
- A critical point in maintaining the export cold chain is the initial cooling of product to -1°C.
- Temperature impacts product shelf life at any point in the supply chain. Sharing data with other supply chain participants directly improves the temperature control and operational decisions, positively impacting shelf life, quality, and brand.

Benefits to industry

- Increased sales volumes (7x)
- Reduction in freight costs saving $3.82 / Kg
- Reduced rejections
- Brand protection and enhancement
- Builds relationships between supply chain partners
- Reduced insurance premiums
- Maintaining Australian Competitive advantage
- Supports more beneficial market access protocols

Future research and recommendations

- Implement an industry 'shelf life lost per day' metric as an easy comparison of how well a cold chain is performing. This metric moves attention away from speed or temperature to a combination of both in one simple metric. When combined with data sharing, this can lead to a more informed decision on stock rotation and management of promotion sales, managing a QIQO (quality in, quality out) rather than FIFO.
- Tracking temperature and location of red meat export shipments has multiple benefits and should be undertaken to minimise product damage, maximise shelf life and enhance brand reputation
- Future ability to enter a processor-specific starting microbiological count to give a more accurate shelf life. A low microbiological count will help with longer shelf life, although cold chain control is more important.

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1. Background

The MLA shelf life model for Vacuum pack (VP) chilled beef and lamb has been developed and tested over the last 5 years (ref). The complex algorithm takes a starting micro count and then applies the continuous product temperature readings to calculate the remaining shelf life of the product at any point in the supply chain. Key findings from testing to date have shown -0.5°C is the optimum temperature to deliver shelf life loss in real time, eg 1 day of shelf life lost per 24 hour period. MLA recommends ideal shipping and storage temperature of red meat is -0.5°C.

To maximise shelf life, the associated reputation for quality, and brand reputation to importers of Australian export meat, ideal temperatures of -0.5°C should be maintained and the impact of higher temperatures should be well understood to assess risks and potential product impact.

Australian red meat has a competitive advantage in the quality of its processing facilities and low CFU count on export product. The Global trend is towards improving processing facility standards and consequently lower CFUs (Sumner, Vanderlinde et al. 2021) so to maintain Australian competitive advantage, shelf life must be maximised by optimising temperature control.

Red Meat export supply chains are inherently complicated, fragmented, and diverse. This is due to:

- the extensive supply routes required,
- the multiple participants and points of changeover,
- the multiple or non-existent data sets from multiple ownership changes, and
- the decay of the food product itself.

Temperature control can often suffer due to these factors, but it is difficult to know where this occurs, for how long and who is responsible. Current approaches to cold chain tracking, i.e., monitoring temperatures and time in the supply chain, have provided inadequate outcomes when trying to view the full end-to-end journey. Solutions are often compromised because of the trade-off in cost, data accuracy, infrastructure requirements, frequency of upload and data interpretation. USB or gateway devices are often lost in the chain along with the valuable data collected, or where data is uploaded it is not in an intuitive format and lacks meaningful insights (e.g. raw CSV). Additionally, nearly all of the current approaches require manual input and can be highly prone to misuse and erroneous data.

In contrast to existing approaches, the Escavox solution captures temperature and location in near real time from the full end to end journey of the primal from processor to end customer without reliance on gateways or manual set up. The data is collected whilst minimising touchpoints and automating as many functions as possible in the collection and interpretation. This results in:

- reduced reliance on people to facilitate the data collection process, reducing costs and errors,
- continuous analysis of the full end to end journey of the food product itself rather than a specific part of the supply chain,
- insightful data visualisations following advanced data analytics,
- enabling more informed decision making

Integrating the shelf life algorithm with the Escavox system shows where issues in the cold chain occur and the impact on the shelf life and quality of the product.

This project aims to investigate and demonstrate the crucial variability points within the primal export cold supply chain from abattoir to importer.

2. Objectives

This study's main objective was:

- Use real-world examples of Australian red meat exports to identify crucial variability points within the cold supply chain from abattoir to arrival at importing country.

Other objectives were:

- Investigate the current cold supply chain of red meat to a variety of export sea and air freight markets.
- Calculate the shelf life of each carton tracked in the study and provide real use case of MLA shelf life algorithm
- Investigate the variability between shelf life outcomes from air and sea freight and prove or disprove the hypothesis that air freight delivers a longer shelf life for the consumer.
- Identify any temperature incursions in the cold supply chain to provide data for any improvement or changes in practice to improve shelf life and quality of red meat.

3. Methodology

3.1 Participants

A broad cross selection of more than 20 exporters in beef and lamb from around Australia participated in this study. A total of 1000 cartons of red meat were tracked through unique supply chain journeys worldwide, by sea or air to 22 countries.

A sample of the supply chains that form the Australian export market were monitored and analysed. As red meat exports have a lengthy and complicated supply chain process, for this report we simplified the supply chain for comparable analysis (abattoir/freight forwarder, transit, destination country). Australia's four largest meat export markets are the Middle East, South Korea, Japan, and North America. Therefore, the focus of this analysis was on these markets. In total, seven export markets were analysed (the USA, the Middle East, Singapore, South Korea, Canada, Japan, and Taiwan).

3.2 MLA shelf life prediction model (SLA)

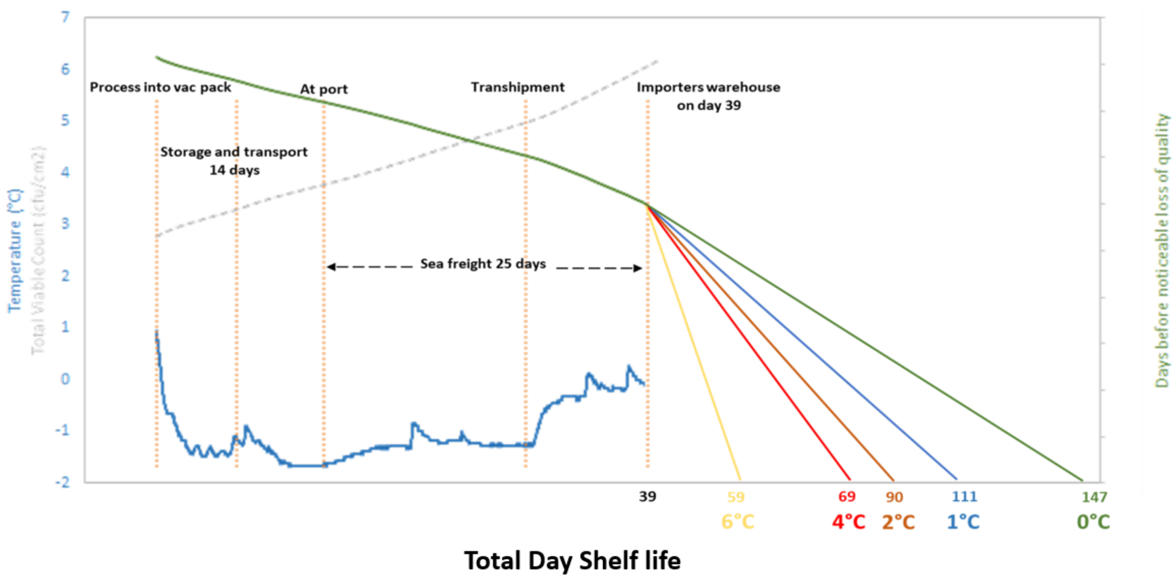
Shelf life of red meats can be affected by several factors. Extending these products' shelf life depends on two main factors: good plant hygiene to restrict initial microbial inoculation levels and storing meat at low temperatures. Based on these two factors, the University of Tasmania (Utas) and the MLA developed a shelf life prediction model for vacuum-packed (VP) beef and lamb primals (V.MFS.0402).

The algorithm output is a forecast of remaining shelf life days when held at a consistent temperature. The default temperature is -0.5°C as this has been proven to yield 1 day of shelf life loss for every 1 day in the supply chain. However, the model can also show the variable impact of holding the product at any consistent temperature.

Previous work published by MLA has demonstrated that shelf life is significantly impacted by temperature. For example, previous work has demonstrated that if the product is stored at -0.5°C, it loses one day per day of storage. However, if the storage temperature was 0.5°C, the days lost become 1.5 days per one day of storage.

For example, in Figure 1 you can see that the remaining shelf life days when red meat is held at 0°C is significantly more than if red meat is held at 4°C. Although both of these temperatures are within the ideal best practice range, it can be easily seen that higher temperatures within this range have significant impact on the rate of shelf life loss.

Figure 1. Predicted shelf life remaining at different temperatures



3.2.1 Microbial starting values

Starting microbial concentration on beef primals was set to 100 cfu/cm^2. Lamb primals were set to a starting microbial concentration of 300 cfu/cm^2. This value was based on the 90% national microbiological results from the National Microbiological Database for lamb and steer/heifer. Standardisation of microbial concentrations was intended to remove variability around processors and allow for meaningful shelf life comparisons between individual export destinations. It is important to note that microbe levels can differ significantly between different processing plants.

With a starting micro count of 100 cfu/cm^2, Beef shelf life at -0.5°C has a maximum of 175 days, for lamb at -0.5°C with starting micro of 300 cfu/cm^2, shelf life maximum is 94 days.

In the results section, we review the impact of multiple different starting micro counts and the impact on shelf life. Note that it is possible to tailor the starting microbial number to a specific processor in a live system to give a more precise shelf life prediction.

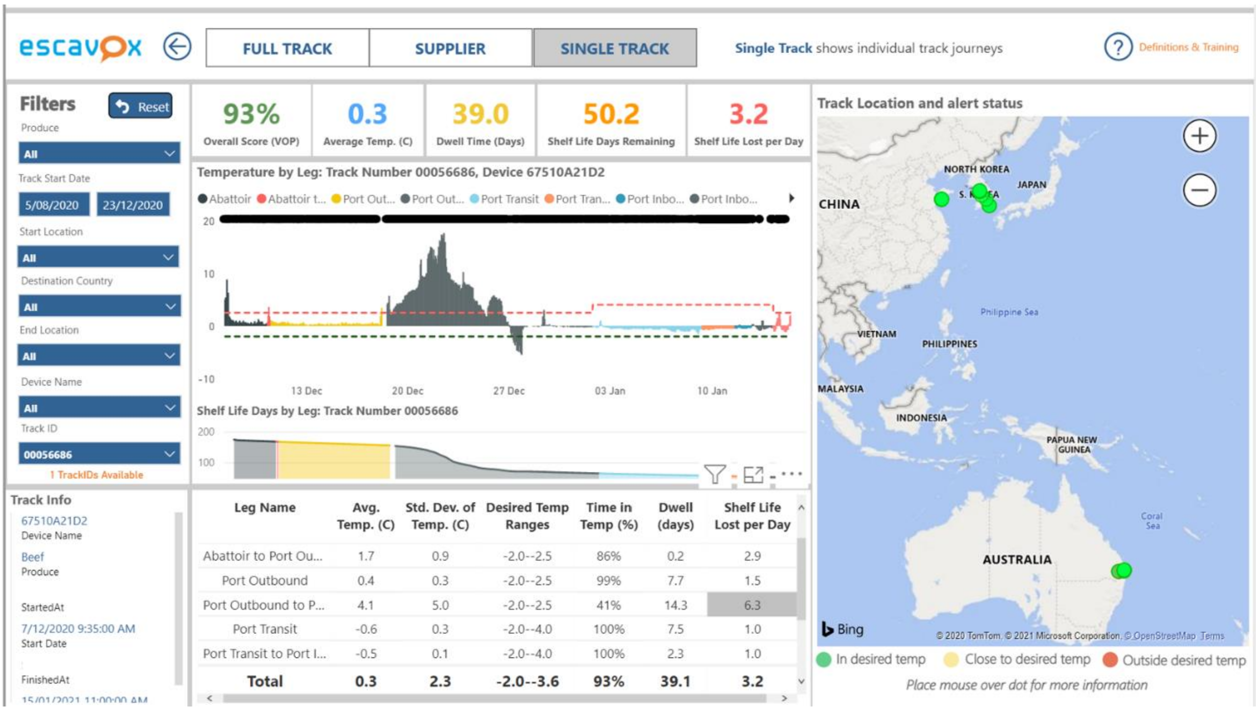
3.3 The Escavox platform

Escavox is a fresh food knowledge business that provides services and analytics to help businesses monitor, understand and optimise their cold chains' performance. Blue Box trackers collect live temperature, time, and location data, which automatically uploads and gives live updates. The Track Logic then processes the collected data to provide critical real-time analysis.

3.3.1 Escavox automated Track Logic

The Escavox platform breaks the supply chain into stages that are meaningful to the user. Track logic automatically segments the live location of the end to end journey (the track) into stages (legs) such as processor, freight forwarder, port, importer. Outputs generated in Escavox reporting such as dwell time, shelf life, legs and temperature are visualised so the user can easily understand the impact of their cold chain (Figure 2).

Figure 2. An example of a track as viewed on the Escavox platform. Note, although not all location points are given, data is continuously collected and uploaded.



The easy visualisation of the data means variables such as how quickly the product moved from location to location can be easily interpreted. Other important analytics include the temperature at any given stage of the supply chain and who was responsible for the product at a particular point in time. The track logic system can also pinpoint potential factors in the cold chain that impact shelf life of red meat. All of these are useful tools in delivering the objectives of this project.

3.4 Escavox Track Logic combined with the MLA shelf life prediction model

The MLA shelf life prediction model gives the shelf life lost in a journey (track) to date and the remaining shelf life at a point in time when held at a specific temperature. A key point is that the remaining shelf life prediction varies according to the temperature it is held at.

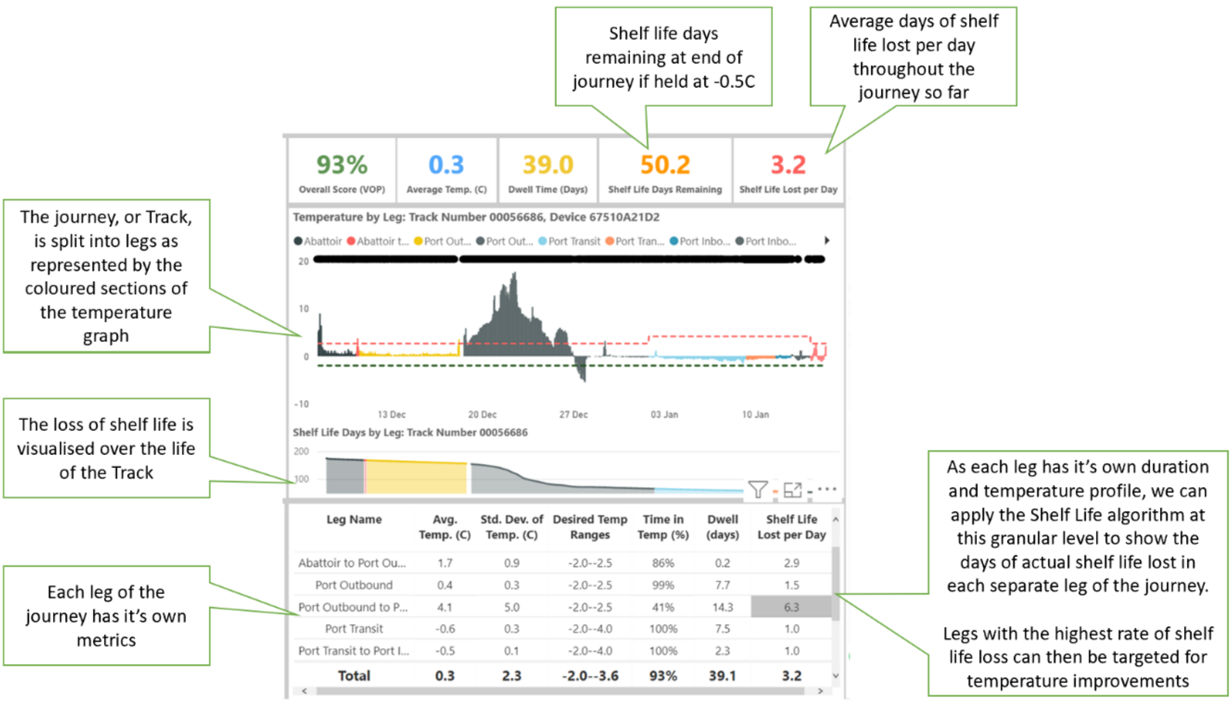
When we apply the shelf life model alongside the Escavox Track Logic, we get a more detailed shelf life breakdown and can determine the rate of shelf life loss in each of the legs of the track. These analytics makes it easier for the user to identify and target breakages in the cold chain resulting in more significant shelf life loss.

MLA's shelf life prediction model was integrated into the Escavox system and visualised on the MyTracks platform to predict remaining shelf life at -0.5ºC during the supply chain from the abattoir/freight forwarder until arrival at the destination country importer and in some cases beyond. Figure 3 demonstrates key information placement in the Escavox platform.

Each of the red meat tracks had its own unique journey through the supply chain, showing multiple legs of the journey and the shelf life loss in each leg.

For analytical purposes, each track was then broken up into abattoir/processor, transit, and importer using the Escavox Track Logic. For each country, we compared several factors, all of which demonstrate the variability in cold supply chains.

Figure 3. Visualisation of the outputs generated in Escavox reporting



3.4.1 Qualification and comparison of tracks

Each track was compared and analysed for the following factors; then, the complete data set was broken down by country and freight type (sea or air):

- Average shelf life lost per day – this is the key metric as all tracks can be compared on this one statistic, regardless of route or journey time
- Length of the journey to the importer
- Actual shelf life lost v's days in transit
- Average temperature of each track
- Predicted total shelf life days of product when held at either -0.5°C or 2°C on arrival at importer
- Whether the product was predicted to achieve total 90 days shelf life (beef) or 70 days shelf life (lamb) when held at 2°C after arrival at importer

Tracks were also classified as good, average, and bad, as seen in Table 1. This classification was based on several interacting factors, including the average actual temperature and average shelf life lost per day as analysed using the Escavox platform.

Table 1. An example of good, average and bad tracks

Beef				**Predicted Total Shelf Life when held at stated temperatures upon arrival at the importer**		
	Total days to importer	*Actual Average Temp (°C)*	*Average Shelf-life lost per day*	Total shelf-life days at -0.5°C	Total shelf-life days at 2°C	Days remaining if achieving 90 days at 2°C
Good	44.8	-0.9	0.5	172.4	92.7	2.7
Average	47.8	0.0	1.2	164.2	91.5	1.5
Bad	40.8	1.2	2.0	133.0	75.4	-14.6
Average of all country tracks	9.8	147.3	*62.8*	-28.5	2.4	3.4

The first three columns represent actual data gathered by the Escavox blue box trackers. The final three columns display predicted shelf life remaining at -0.5°C and 2°C (temperatures commonly used at importers). The last column demonstrates how many days would remain after removing 90 days from the predicted 2°C shelf life.

3.4.2 Placement of Escavox trackers

This project utilised Escavox blue box trackers and the Escavox MyTracks platform to track the progress of cartons of red meat through the supply chain. To track cartons, an Escavox blue box tracker was placed into the cartons at the processor stage. There was some variance regarding the trackers' placement (placed either at the boning room, loadout room or freight forwarders). The

Escavox tracker monitored temperature, time, and carton location from abattoir/freight forwarder to the retailer or importers distribution centres in international markets.

Where possible, most participants were requested to place the Escavox tracker inside the meat packets so that the tracker would show the drop of temperature as the red meat was cooled before export and provide a closer estimate of core meat temperature. In most scenarios, cartons were unmarked so that tracker can provide a true reflection of meat temperature with no special handling at the processing plant, loading of carton or importer.

Participants used between 1 and 3 trackers per container to understand temperature variations within the container and ensure a good sample size of end customers once the importer sold the carton.

4. Results

4.1 Overall results

Key findings:

- All channels show high levels of variability in temperature storage, handover points and duration. There are no 'good' routes
- Product moved by air has a much more variable rate of shelf life loss compared to product moved by sea. On average, product moved by sea loses 1.6 days of shelf life for every day in transit, whereas by air this is 3.6 days of shelf life.
- Average Beef Temperatures to importer were 0.7 +- 1°C, average lamb temperatures were -0.1 +- 1°C
- The more variable the temperature, the higher the rate of shelf life loss.
- The correlation between temperature control and shelf life loss is stronger than the correlation between journey time and shelf life loss
- Moving and storing red meat consistently at or below -0.5°C results in a rate of shelf life loss per day of <1. Moving or storing red meat consistently above -0.5°C results means shelf life is lost at a faster rate than 1 day per day of journey time.

The 1000 tracks in the study were exported to 22 countries. To compare and contrast the various journeys and investigate the variability differences between air and sea freight outcomes, tracks were grouped by the most numerous export end locations. These locations were the United States of America, the Middle East, Singapore, South Korea, Canada, Japan, and Taiwan.

For each grouping of tracks, the following areas are analysed and discussed.

1. good, average and bad tracks
2. percentage of tracks meeting the 90 days shelf life requirement
3. comparison of sea and air shipments to test the hypothesis that air freight provides longer shelf life product

When examining tracks within the reports generated by the Escavox platform, those with lower average temperatures tended to have fewer temperature excursions and increased predicted shelf life. As discussed below, the temperature has a significant impact on shelf life days.

When analysed as a whole, it can be observed how variable beef (Table 2, Figure 4, A) and lamb (Table 3, Figure 4, B) exports can be regardless of the length of the journey or end destination. Almost all beef tracks analysed were able to achieve 90 days shelf life upon arrival at importer if they were held at -0.5°C for the track's remaining duration. Increasing the temperature to 2°C was shown to have a significant detrimental effect on the ability of beef products to achieve 90 days shelf life. This result shows the importance of maintaining a good cold chain through the export journey; both pre-importer, to give the product the highest shelf life on arrival, and through the importer to maintain distribution options and protect the brand of Australian red meat.

Note, with South Korea, tracks were particularly variable (some excellent tracks and some very poor tracks). Although the averages from the key metrics were generally high, the percentage of tracks achieving 90 days shelf life were comparably lower than other countries analysed.

Table 2. Analysis of key metrics for Australian beef exports

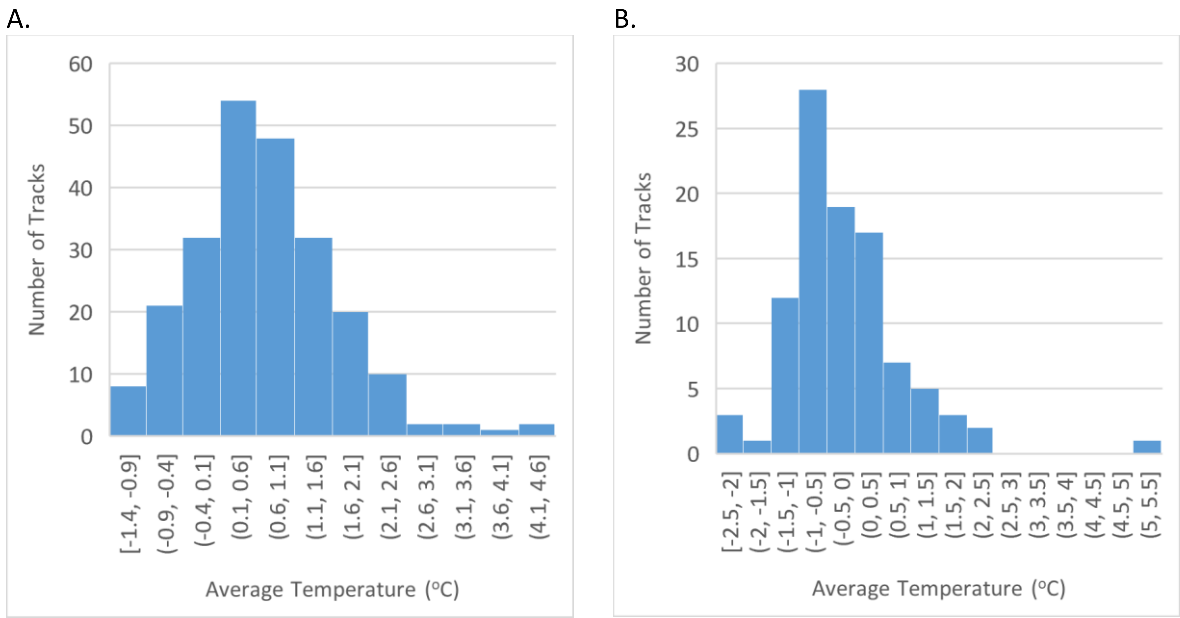
Beef Tracks				**Predicted Total Shelf Life when held at stated temperatures upon arrival at the importer**			
Country	*Average total days to importer*	*Actual average Temp (°C)*	*Average shelf-life lost per day*	Average total shelf-life days at -0.5°C	% tracks achieving 90 days at -0.5°C	Average total shelf-life days at 2°C	%tracks achieving 90 days at 2°C
USA	34.2	1.2	2.2	145.6	100%	76.1	24%
Middle East	43.4	0.7	1.5	152.9	100%	84.5	29%
South Korea	31.9	0.6	1.7	158.0	97%	79.3	6%
Canada	15.0	2.4	3.1	139.2	100%	61.7	0%
Japan	27.1	0.5	1.7	158.0	100%	76.3	4%
Taiwan	31.5	0.8	1.8	157.0	100%	78.7	7%

Lamb tracks were more variable than beef tracks. However, exports to most countries attained over 90% of tracks achieving 70 days shelf life upon arrival at importer if they were held at -0.5°C for the duration of the track (Table 3). While increasing the temperature to 2°C decreased the amount of product achieving 70 days shelf life upon arrival at the importer, overall, lamb tracks performed better than beef tracks at this temperature.

Table 3. Analysis of key metrics for Australian lamb exports

Lamb Tracks				**Predicted Total Shelf Life when held at stated temperatures upon arrival at the importer**			
Country	*Average total days to importer*	*Actual average Temp (°C)*	*Average shelf-life lost per day*	Average total shelf-life days at -0.5°C	% tracks achieving 70 days at -0.5C	Average total shelf-life days at 2°C	%tracks achieving 70 days at 2°C
USA	44.6	0.1	1.1	77.3	75%	59.2	19%
Middle East	38.2	-0.2	1.1	92.8	91%	62.6	31%
Canada	54.0	-0.5	1.0	94.3	100%	72.0	65%
Japan	33.0	-0.1	1.1	92.0	100%	59.4	0%

Figure 4. Distribution of average temperatures for each beef (A) and lamb (B) track in the study



4.1.1 Average shelf life lost per day

Average shelf life lost per day is a key metric in this report when analysing red meat export tracks. This metric is crucial as all tracks can be compared on this one statistic, regardless of route or journey time.

Average shelf life lost per day is calculated by dividing the total calculated shelf life lost in the journey by the total days the journey has taken. If the result is <1, then the journey has resulted in the delivery of a product that actually has more than the stated remaining shelf life days. If the result is >1 then the product is delivered with less than the stated remaining shelf life days.

The calculation was applied to tracks that start at the processor and finish on arrival at the importer.

Figure 5 and 6 are histograms showing the number of beef and lamb tracks and their average shelf life lost per day on their journey from the processor to the importer. Figure 5 shows sea tracks. Figure 6 shows air tracks. The graphs are different sizes in order to show the axis as the same scale and compare the distribution. It is clear that sea tracks provide a more consistent outcome, whereas air tracks have a very flat distribution implying high variability.

For sea we can see that 30% of tracks are under or match the journey time in terms of shelf life lost, but the remaining 70% have a higher rate of shelf life loss of 1 day per day of journey time. The details and root causes for this are discussed in detail in the country sections below.

Figure 6 shows the worst track of a product moved by air loses 9 days of shelf life for every day in the journey. Journey times by sea vary hugely depending on the destination country, but average airfreight shipments were 10 days from processor to importer. In the worst case scenario, this means that although 9 days transit time has passed, the actual impact to shelf life was 90 days lost.

See the Country Analysis sections in the Appendices for more detailed analysis on sea and air tracks to the US.

Figure 5. Distribution of the average days of shelf life lost per day prior to reaching importer for sea freight

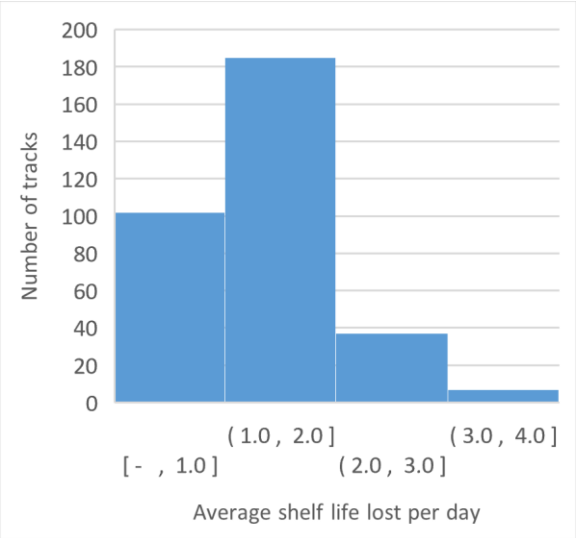
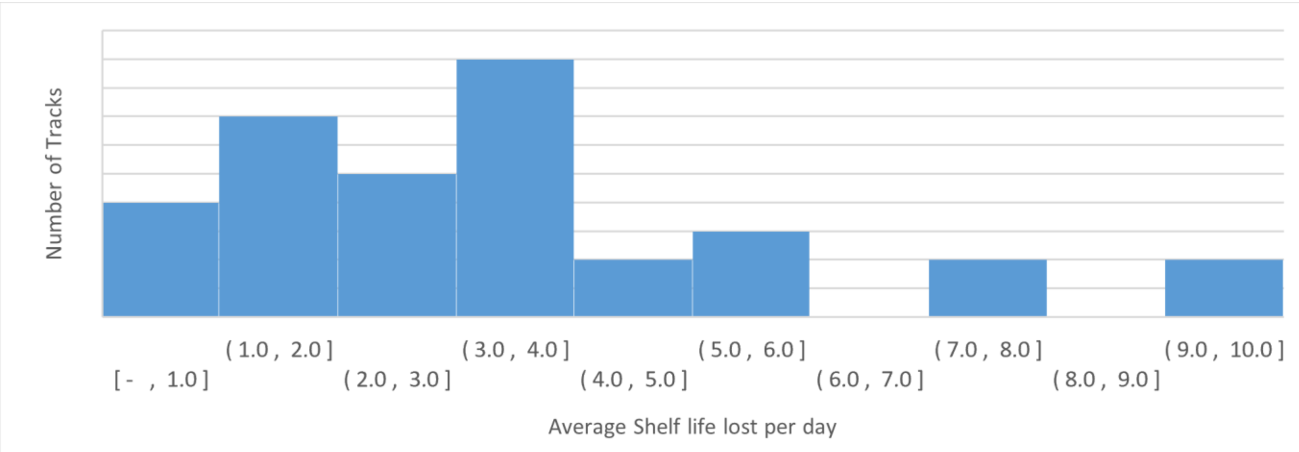


Figure 6. Distribution of the average days of shelf life lost per day prior to reaching importer for air freight



4.2 Case studies

- Comparison of sea and air freight to the US
- Improving lamb exports to the middle east
- How exports can be improved by sharing data with importers

4.2.1 Comparison and analysis of air freight vs sea freight

Key Findings:

1. Generating data that proved sea freight suitability then shared with the retailer resulted in 7x higher volume sales, reduced freight costs of $3.45/kg and enhanced brand reputation.
2. Sea freight exports are able to achieve the same shelf life outcomes as air freight exports.
3. Simple changes in abattoir and reefer temperatures resulted in a shelf life saving of 50 days.

Air freight exports of Australian red meat to the US have been particularly affected by the advent of the COVID 19 pandemic. While this affected many participants in this study, one study participant faced potentially losing a customer due to air freight ceasing to the US East Coast during the pandemic.

When flights resumed, export air freight costs increased to six times the cost of sea freighting the product, up from two and a half times the sea freight cost before Covid. This increase in expense raised concerns that using air freight as an export method would price the product out of the market. To keep their sales channel open, the exporter had to sea freight product. As this was the first time the exporter had used sea freight to the east coast, and shelf life predictions had not previously been applied, the US customer naturally had concerns about the product integrity.

US importer perception is that air freight is the preferred form of transit due to faster delivery yielding a longer shelf life. Through the use of the Escavox trackers and the shelf life prediction model, the study participant ran a number of air freight shipments investigating the variability of shelf life. The average shelf life on arrival at importer was 138 days. The study participant was then open to work with suggested improvements made via Escavox and MLA to test whether they could deliver the same shelf life result from a 60 day sea journey as a 10 day air freight journey to their East Coast customer.

The study participant's first sea freight tracks arrived with 88 shelf life days remaining (Figure 7). Based on the track data, suggestions were made to lower the set temperature of reefer to –2.0°C. Additionally, it was requested that the abattoir could drop the temperature of the product to –1.5°C for transport to cold storage with the aim to maintain a temperature of –1.5°C before the product was loaded into the reefer. The results of these seemingly minor changes are shown below (Figure 8).

Figure 7. First sea freight track, 88 days shelf life remaining on arrival at importer.

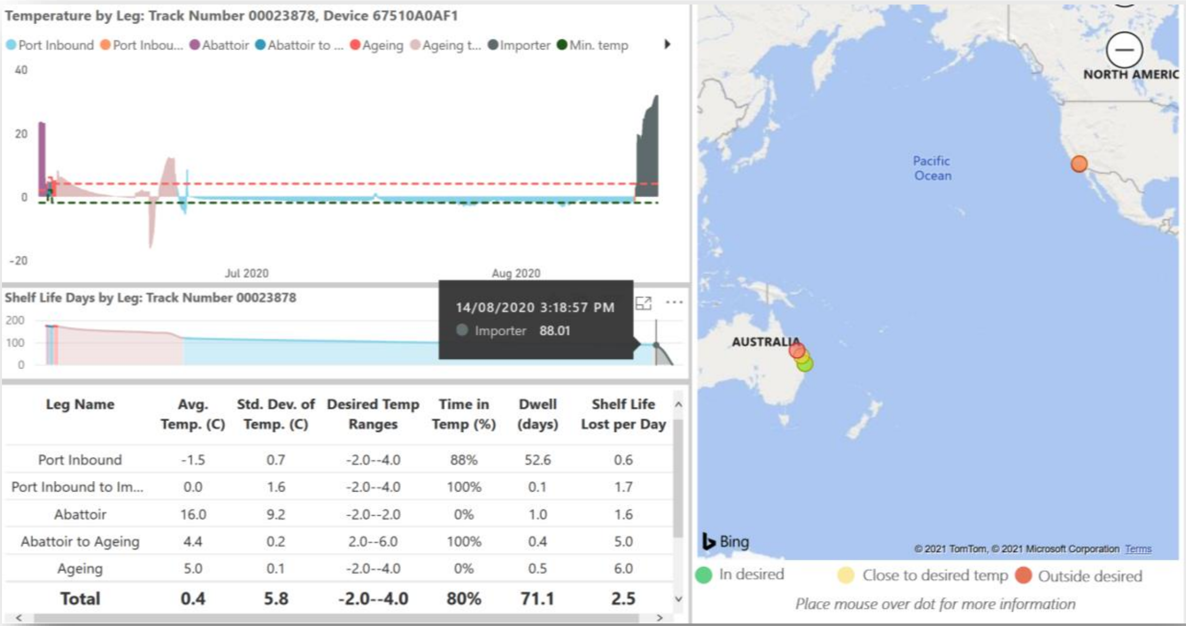
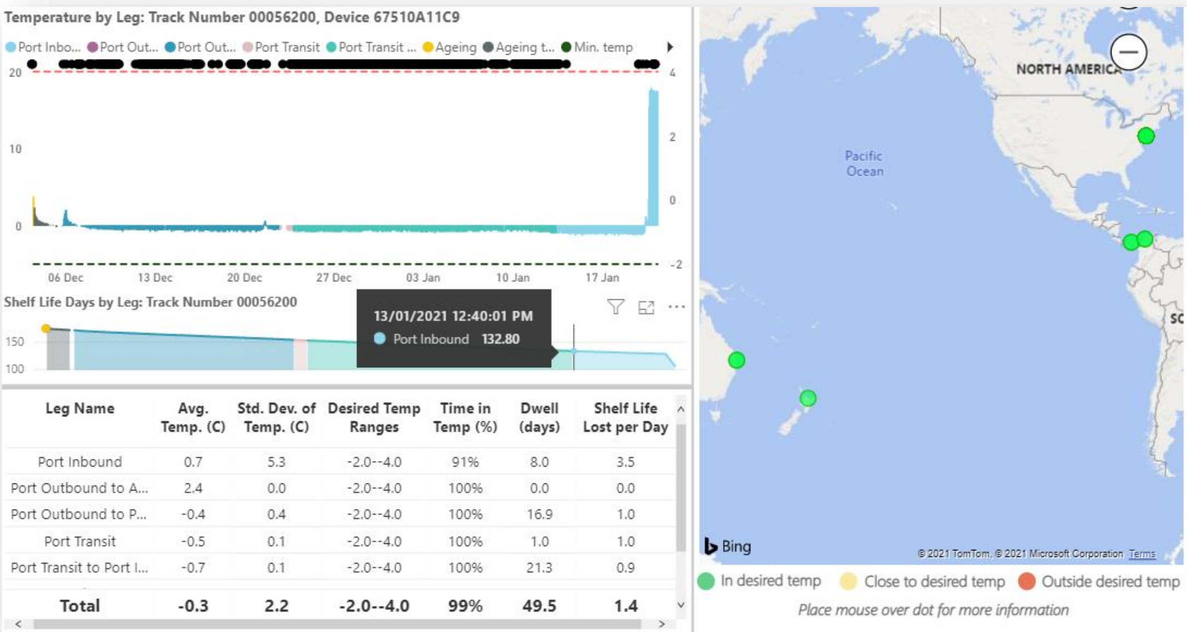
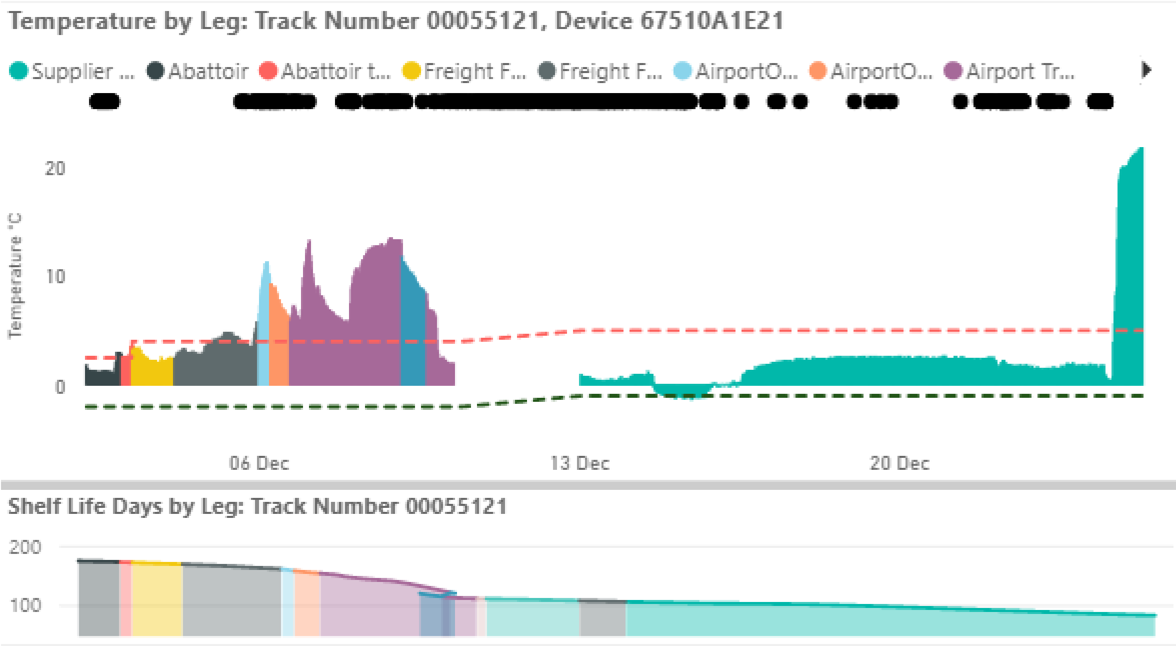


Figure 8. Improved shelf life after changes made to export cold chain.



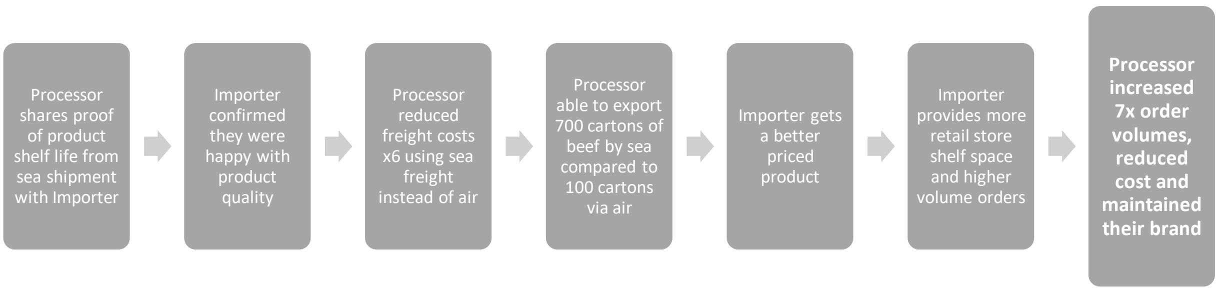
This first shipment with the recommended temperature improvements arrived at the importer with 132 days of shelf life remaining. This was very close to the average result seen with air freight shipments (138 days) but achieved over 60 days rather than 10 days. The high level of change over points and temperature fluctuations in a typical air freight track can be seen in Figure 9 and are very difficult to control, whereas the slow and steady control of sea freight has achieved the same shelf life outcome over a longer time frame.

Figure 9. An air freight track to the US



These changes highlight how communication with supply chain partners, in this case to change storage temperatures and processes, can result in a product with a greater number of remaining shelf life days delivered to a customer/importer. When the tracker was finally removed by the East coast customer, the shelf life model predicted 117 days of shelf life were still remaining with this product.

The participant was able to alleviate any concerns the customer had around the integrity of the product by sharing the data of the export track along with the shelf life predictions. This resulted in several commercial benefits for the participant:



Although at times it can be hard to dispel industry and retail perceptions around shelf life of exports, this case study shows that it is possible to extend shelf life at import country plus have visibility of how product performs with actual data. Validation and sharing of this data with the importer can lead to more uptake of these changes and result in the continued success of Australian red meat exports.

4.2.2 Improving temperature control improves exports at a country level

Key findings:

1. The variability of red meat temperature prior to leaving the processor directly impacts the maintained temperature of the rest of the journey. Product held at -1°C prior to dispatch are able to maintain sub zero temperatures and maintain rate of shelf life loss at <1 day
2. Live visibility in plant is crucial to ensure temperature is optimal prior to leaving
3. It can take 72 hours to chill a primal from 3°C to -1°C
4. Shelf life results validate capability to meet middle east shelf life requirement changes from 70 to 90 shelf-life days for chilled lamb and 70 to 120 shelf-life days for chilled beef

The Middle East is one of the main export destinations for Australian red meat, in particular lamb. The United Arab Emirates makes up a sizable percentage of those exports. Countries in this region have recently extended their shelf life requirements on their food safety protocols, from 70 to 90 shelf-life days for chilled lamb and 70 to 120 shelf-life days for chilled beef.

In addition, Covid 19 has greatly impacted the availability and cost of airfreight and as such this case study was to test and confirm the ability of sea freight to meet these conditions, in particular to investigate if tracking temperature from the boning room would result in an overall improvement of product exported to the UAE.

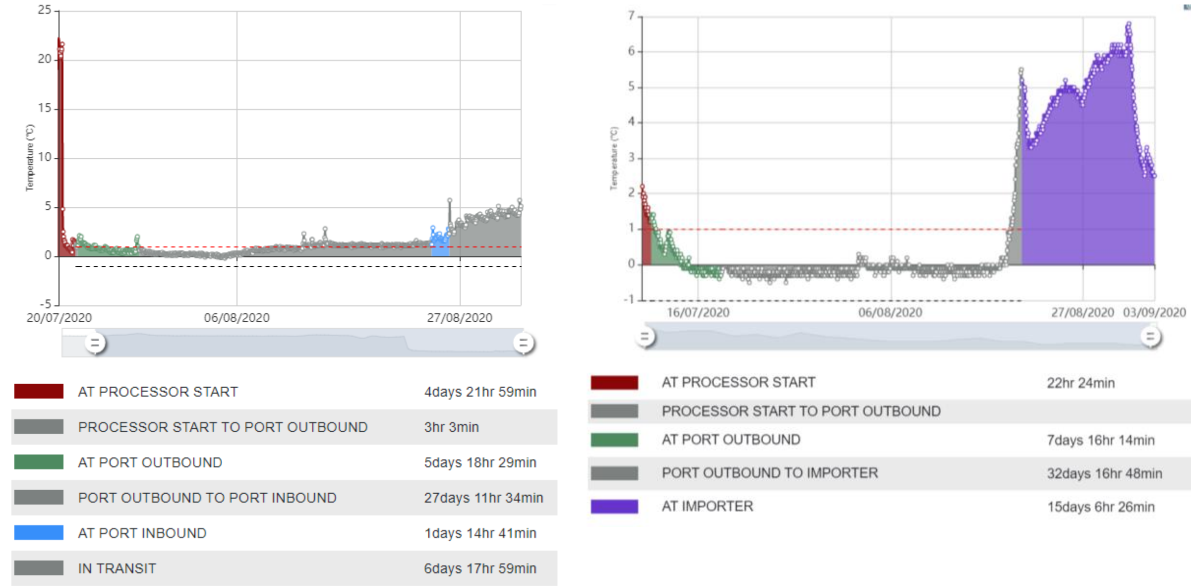
The Escavox tracker was installed in the middle of the VSP packets to ensure temperature data collected is as close as possible to the meat core temperature. The first trackers were placed in and the normal operational process was observed. Temperatures were brought down to 2°C and the primals were loaded for dispatch.

Figure 10 shows two examples of primals shipped having been pre-cooled to 2°C. In both instances the temperature remains consistent when held at port, but in example A the temperature gradually decreases over the first 9 days at sea, indicating a reefer temperature setting of lower than 2°C but the product takes 9 days to adapt to this temperature. The temperature then starts to increase after a stop over in Asia indicating a change to the reefer settings at this time. On arrival in country, the shelf life model showed that Figure 10 (A). had a total of 145 days shelf life when held at -0.5°C, well within the 120 day required, the positive result of an uneventful sea journey.

Figure 10 (B) shows a lamb track. Although the shipment occurs at -0.5°C, The temperature is only reduced to 1.5°C at the Processor and takes 5 days to drop below 0 while waiting at the port. This period of time is critical as significant shelf life was lost. Total Shelf life on arrival in country was 83 days, just under the 90 days specified for UAE. Note that Figure 10 (B) also shows a comparatively high storage temperature at the importer.

Figure 10. Higher loading temperature of tracks resulting in higher overall export temperatures

A. Beef B. Lamb

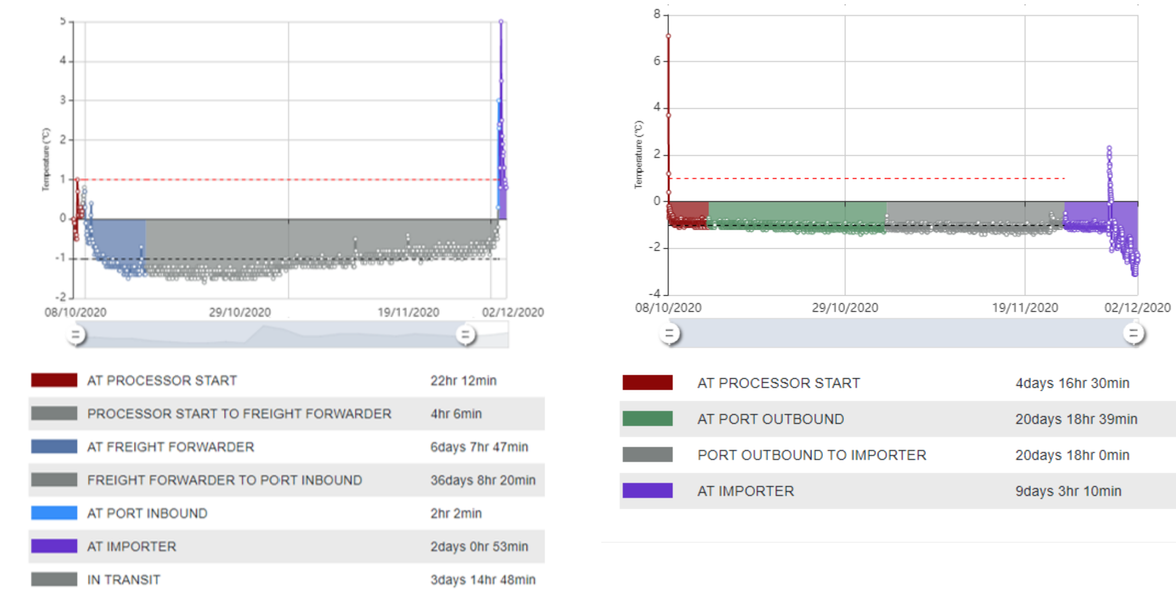


The above two examples (Figure 10) show that the higher loading temperature of the carton is maintained during the entire journey, or that if not pre cooled well prior to dispatch then it can the several days before reaching ideal storage temperature, all of which impact shelf life. Loading product at a higher temperature means the reefer struggles to drop the temperature of the carton. This higher loading temperature then resulted in a higher shelf life loss rate per day for the entire export journey.

Following this discovery, a change in pre-cool protocol was adopted to bring the temperature to -1°C. In other tracks, data has demonstrated that when loading product at -1°C there is a very high probability that the product temperature will be maintained for the entire journey.

Figure 11. Lower loading temperature results in better export tracks

A. Lamb B. Beef

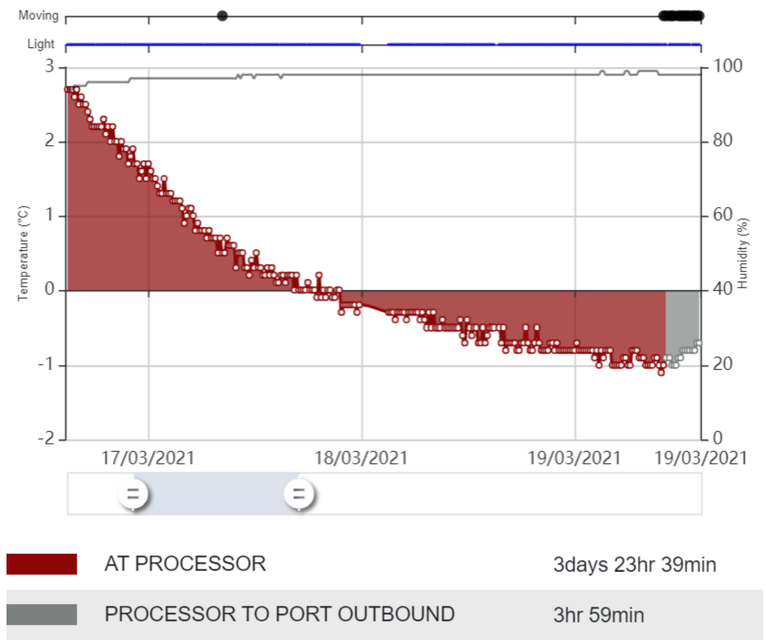


The above examples (Figure 11) show that the lower loading temperature can be maintained for the whole export journey, resulting in minimal shelf life loss per day. Figure 11 (A) shows an increasing temperature, again indicating that the reefer temperature is higher than the loading temperature, but even though the temperature increases, this does not significantly impact the product. The lamb in example A had a total shelf life of 102 days, well in excess of the 90 day requirement.

The beef in Figure 11 (B) had 189 days, so well cooled and controlled that it had hardly lost any actual shelf life. This allows the processor to minimise risk in sea shipments as they are starting from such a strong position. This product would have had a significant advantage if the shipment was delayed at sea or reefer failure occurred.

The data from this study has demonstrated that the best-case scenario temperature control can be achieved when initial temperature of the product is lowered to –1°C, which can then be maintained for entire journey until receipt at importer. As previously discussed, VSP red meat held at -0.5C loses 1 day of shelf life per day in transit.

Figure 12. Live temperature traces from the blast chiller and cold storage rooms



Pilot participants wanted data in real time in order to confirm the temperature dropped to the desired -1°C. However, the remote location of many processers can cause sporadic connectivity with live trackers.

Escavox assisted with the installation of a 3G/4G range extender to provide live connectivity of trackers in blast chiller and other rooms at the processing plant. Improvement of connectivity enabled the processing plant QA team to ensure all product was loaded at the desired temperature shown to deliver optimum shelf life to their customers worldwide. Figure 12 shows the gradual drop in temperature to -1°C, and also shows that at least 72 hours is needed to achieve dropping the temperature from 3°C to -1°C in a normal chiller.

Figure 13. Transfer of containers from plant to port

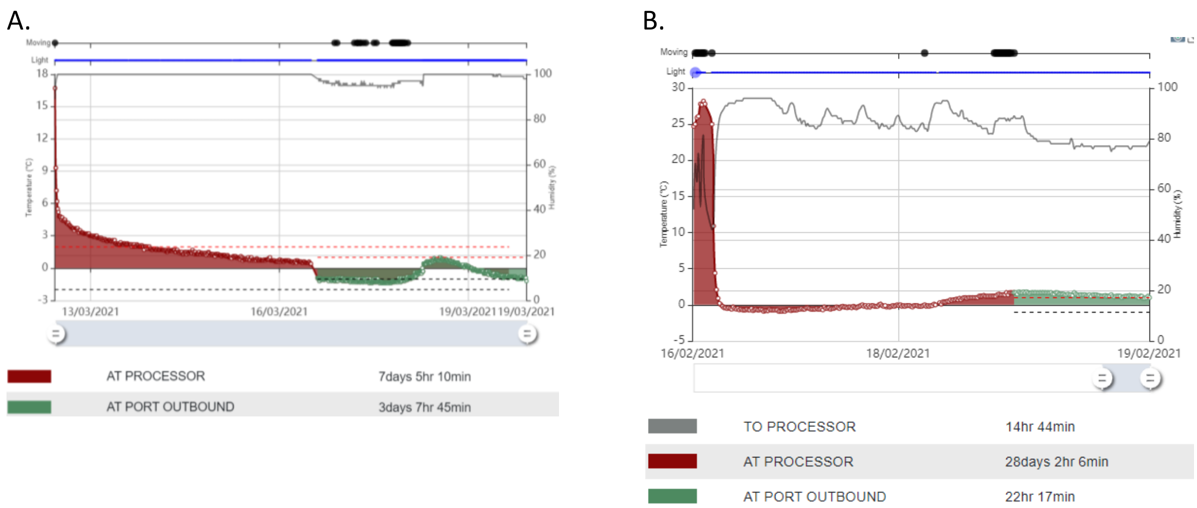


Figure 13***Figure*** shows the transfer of containers from the plant to the port. If the container is removed from the power source, even for a short period of time, there can be temperature spikes. By initially cooling the product to a lower temperature when leaving the plant, many tracks showed if the temperature spiked at loading (as often occurs) the product was more quickly able to drop down back down to that starting lower temp.

These findings were then tested by participants sending product to the UAE (Table 4), resulting in an improvement of average temperature of -1.2°C for the last six months of this study. These improvements resulted from the participants ability to monitor temperature data of product from the boning room and ensure product was at -1°C before packing.

Table 4. Average temperature of customer exports to the UAE over the twelve month study

	Average export temperature (°C)
	Overall export
First six months	0.9±0.9
Last six month	-0.3±0.8

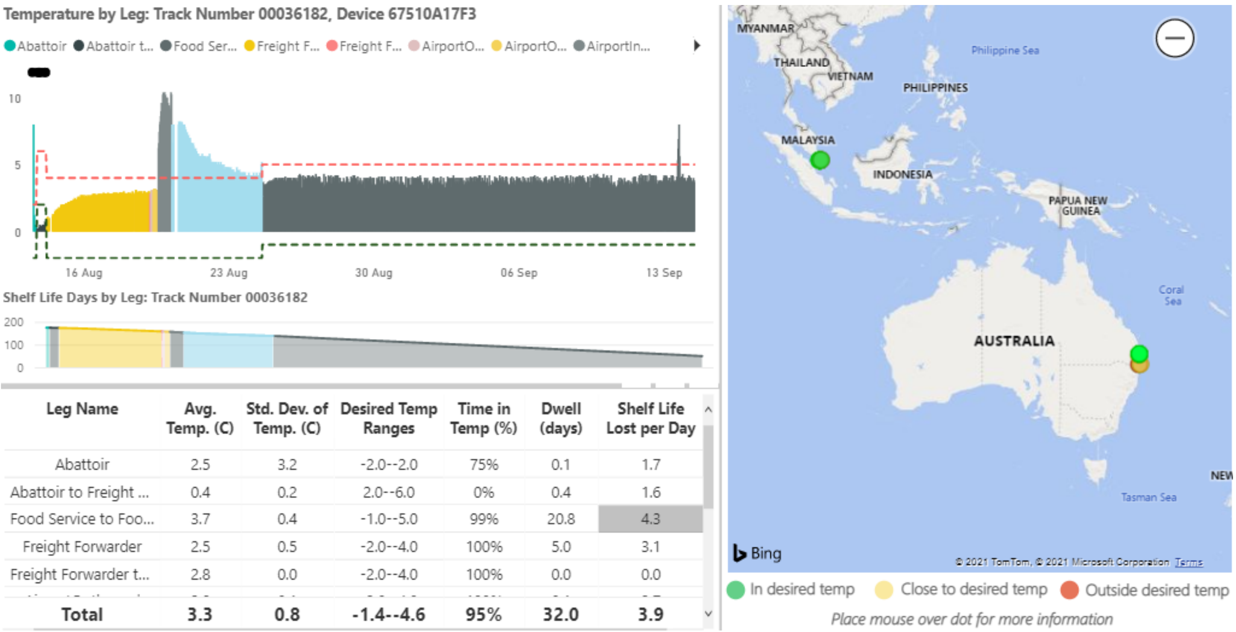
4.2.3 Data transparency improves export products

Key Findings:

1. Sharing cold chain data with Food Service customers and communicating benefits of lowering storage temperatures was positively received and a 1C reduction in storage temp resulted in a 25 day increase in shelf life.
2. The variability of temperature during the long storage period in Food service has significant implications on the remaining shelf life of the primal for that customer.

Tracking the cold export supply chain of Australian red meat presents a unique opportunity for industry to share data with their importers, particularly to show how temperature affects shelf life of the product they purchase. In this example (Figure 14), the exporter has shared their data with their customer (hotel chain) so they can understand the impact on shelf life.

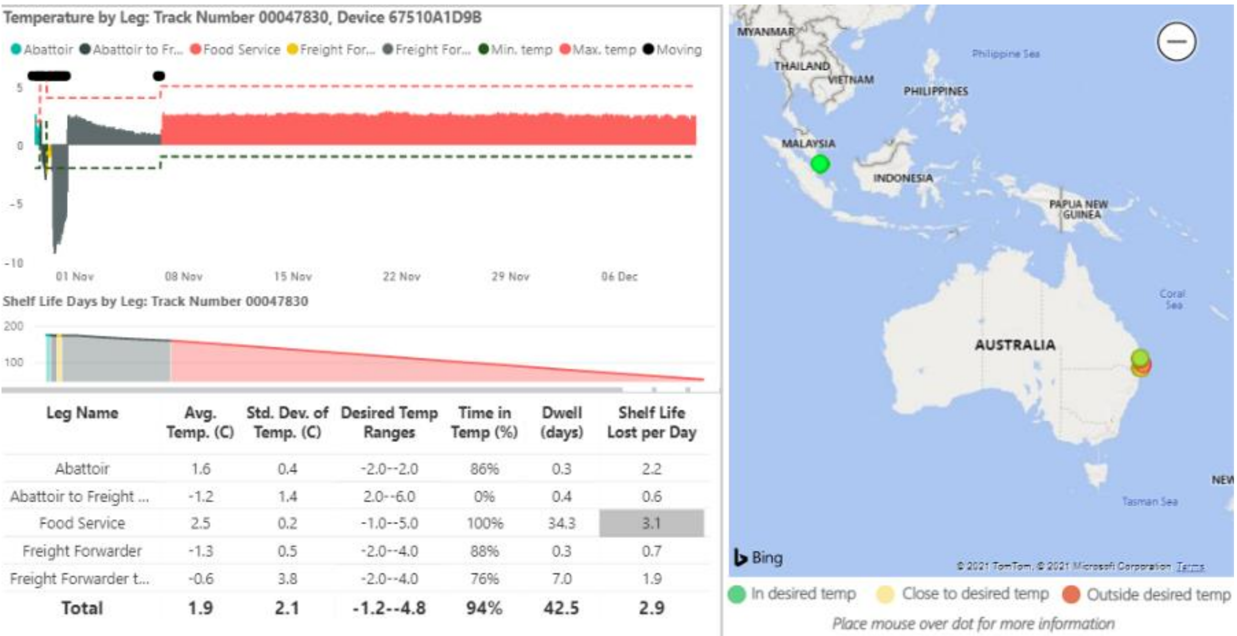
Figure 14. **An example of data shared by an exporter with their importer, a hotel chain**



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	2.5	3.2	-2.0--2.0	75%	0.1	1.7
Abattoir to Freight ...	0.4	0.2	2.0--6.0	0%	0.4	1.6
Food Service to Foo...	3.7	0.4	-1.0--5.0	99%	20.8	4.3
Freight Forwarder	2.5	0.5	-2.0--4.0	100%	5.0	3.1
Freight Forwarder t...	2.8	0.0	-2.0--4.0	100%	0.0	0.0
Total	**3.3**	**0.8**	**-1.4--4.6**	**95%**	**32.0**	**3.9**

This track shows product maintained at a temperature of 3.7°C in a food service cold room, resulting 4.3 days of shelf life lost per day of storage. The rate of shelf life loss was highlighted to the hotel partner to demonstrate the opportunity cost of lowering the storage temperature, with the aim of helping the hotel partner increase the shelf life of the imported red meat.

Figure 15. Decreased temperature in a food service cold room



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	1.6	0.4	-2.0--2.0	86%	0.3	2.2
Abattoir to Freight ...	-1.2	1.4	2.0--6.0	0%	0.4	0.6
Food Service	2.5	0.2	-1.0--5.0	100%	34.3	3.1
Freight Forwarder	-1.3	0.5	-2.0--4.0	88%	0.3	0.7
Freight Forwarder t...	-0.6	3.8	-2.0--4.0	76%	7.0	1.9
Total	**1.9**	**2.1**	**-1.2--4.8**	**94%**	**42.5**	**2.9**

Communication with the hotel partner resulted in the temperature of the cold room at food service being lowered. The resulting track (Figure 15) has lower average temperature at food service of 2.7°C days resulting in an average of 3.1 days of shelf life lost per day. That's a reduction of 1.2 shelf life days lost per day by decreasing the average storage temperature in the Hotel cool room.

Over the same 21 days storage period, this decrease in temperature added an additional 25 days shelf life to the hotel partners chilled beef product. One of the key benefits for this Food Service importer was around reduced waste for their sustainability metrics.

Escavox and MLA provided some modelling where cool room storage was lowered even further to 1.0°C which demonstrated that additional shelf life days could be achieved (V.MFS.0449). These tests validated the opportunity cost of achieving longer shelf life in product, reducing shrink of poorly controlled product and reducing food waste, far outweighs the additional electricity costs associated with the lower temperatures recommended for cold room storage.

4.3 Analysis of Microbial Starting Values

Key finding:

- Product storage temperature has significantly greater impact on shelf life loss than starting microbial counts.

As previously discussed, shelf life of red meats can be affected by several factors. Extending these products' shelf life depends on two main factors: good plant hygiene to restrict initial microbial inoculation levels and storing meat at low temperatures.

We hypothesised that starting microbial values would be less critical when attempting to minimise shelf life loss than maintaining a low product temperature. To test this hypothesis, beef and lamb tracks were selected (one good, average and bad track for each product type) and the rate of shelf life loss was calculated from five different microbial starting values (microbial concentrations of 10, 30, 100, 300 and 1000 cfu/cm^2).

4.3.1 Microbial impact on beef tracks to South Korea

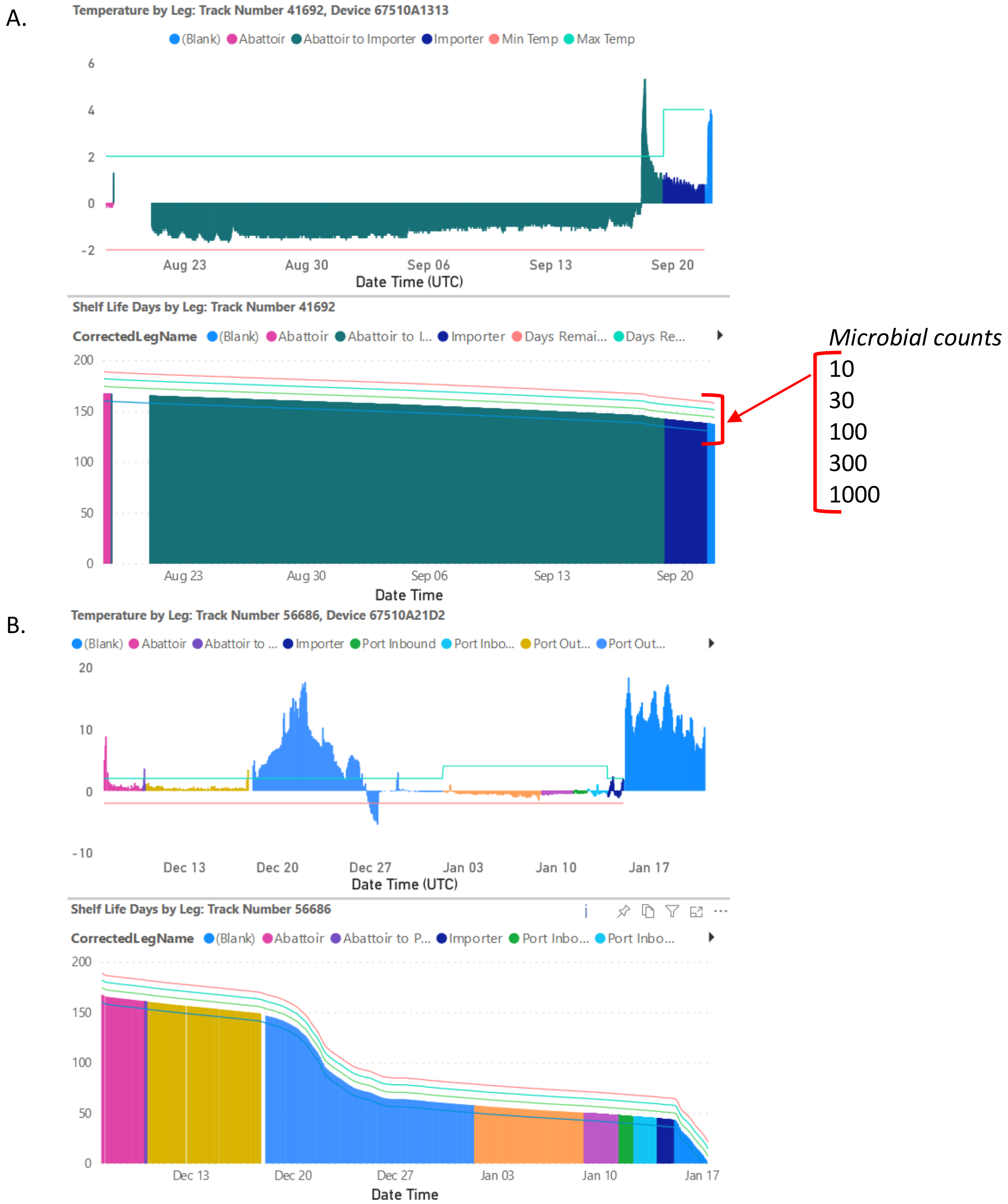
Beef tracks to South Korea were selected for this analysis as it is a key export region, in close proximity to Australia and has a well-defined supply chain. Figure 16 shows the temperature traces and shelf life predictions for a good (A) and bad (B) track to South Korea. The predicted remaining shelf life days depending on the starting microbial values can be found in Table 5. As can be seen, if a good track has good temperature control, even if it has a high starting microbial value, there will be more shelf life days remaining than a bad temperature controlled track with an excellent starting microbial value.

Table 5. Predicted remaining shelf life when held at -0.5C for good, average and bad beef tracks to South Korea

Microbial starting value (cfu/cm^2)	Predicted shelf life days remaining		
	Good	Average	Bad
1000	**134.77**	110.76	37.53
300	142.23	118.26	44.97
100	148.96	125.08	51.84
30	156.43	132.52	59.31
10	163.35	139.34	**66.07**

As can be seen in Figure 17, improving the microbial starting value can improve the shelf life of the product. However, as previously discussed, lowering temperature can result in the delivery of a product that actually has more than the stated remaining shelf life days.

Figure 16. Good (A), and bad (B) beef tracks to South Korea with variable microbial counts



The 'bad' beef track to South Korea in Figure 16 (B) highlights how temperature can have a significant impact on shelf life as shelf life is rapidly lost due to an increase in temperature. This trend occurs regardless of starting microbial value. This correlation of bad temperature control resulting in greater loss of shelf life regardless of microbial value can also be seen in Figure 18.

Figure 17. Days of shelf life gained for beef exported to South Korea

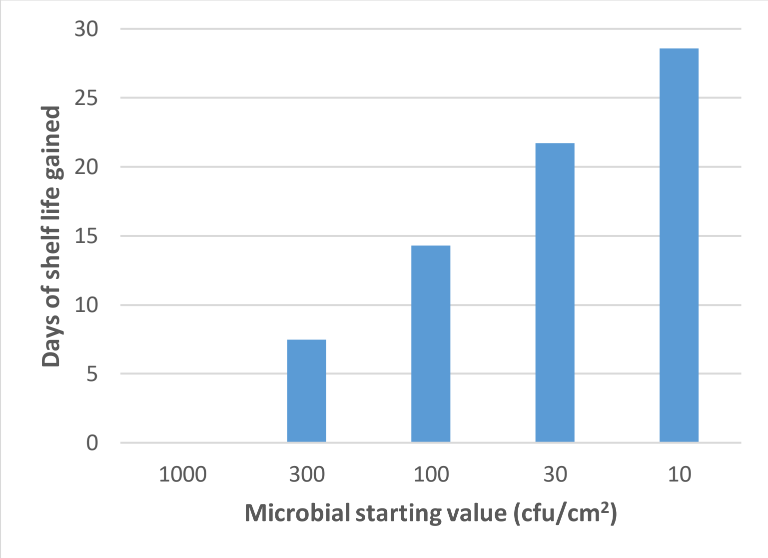
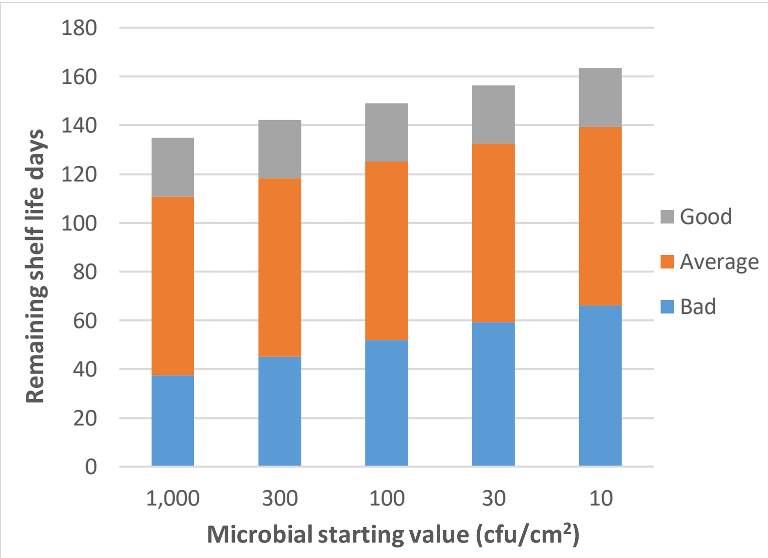


Figure 18. The impact of microbial starting values on remaining shelf life days on tracks to South Korea with varying temperature control.



4.3.2 Microbial impact on lamb tracks to the Middle East

Lamb tracks to the Middle East displayed a similar trend to the beef tracks previously analysed in that product temperature had a greater impact upon shelf life loss than microbial starting values. Tracks to the Middle East were selected for this analysis it is one of Australia's most important export markets for lamb. Figure 20 shows the temperature traces and shelf life predictions for a good (A) and bad (B) track to the Middle East. The predicted remaining shelf life days depending on the starting microbial values can be found in Table 6.

As was observed with beef tracks, if a lamb track has good temperature control, even if it has a high starting microbial value, there will be more shelf life days remaining than a bad temperature controlled track with an excellent starting microbial value. This difference in shelf life is not as large as the difference observed with beef tracks, as lamb has a lower starting shelf life. Fewer days of shelf life are gained for lamb exported to the Middle East when improving the starting microbial count (Figure 19).

Table 6. Predicted remaining shelf life for good, average and bad lamb tracks to the Middle East.

Microbial starting value (cfu/cm²)	**Predicted shelf life days remaining**		
	Good	**Average**	**Bad**
1000	**37.46**	34.54	16.22
300	41.66	38.09	20.48
100	44.45	41.91	24.24
30	49.61	47.95	28.43
10	53.44	50.57	**32.12**

Figure 19. Days of shelf life gained for lamb exported to the Middle East

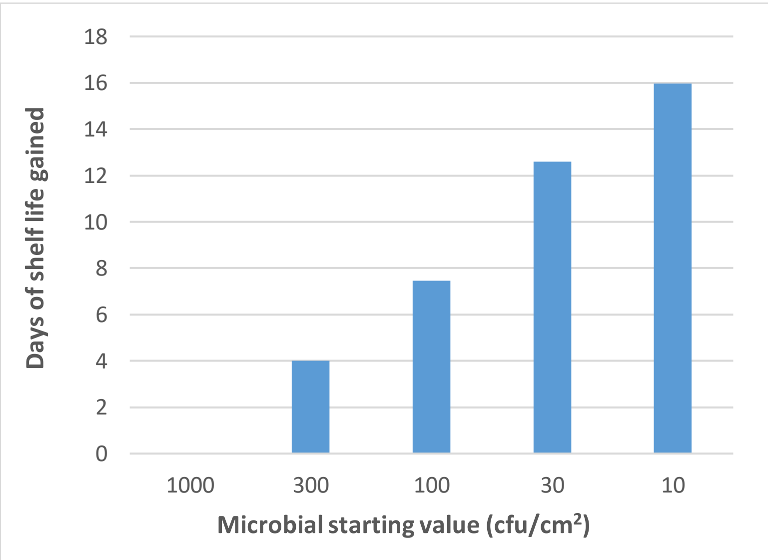
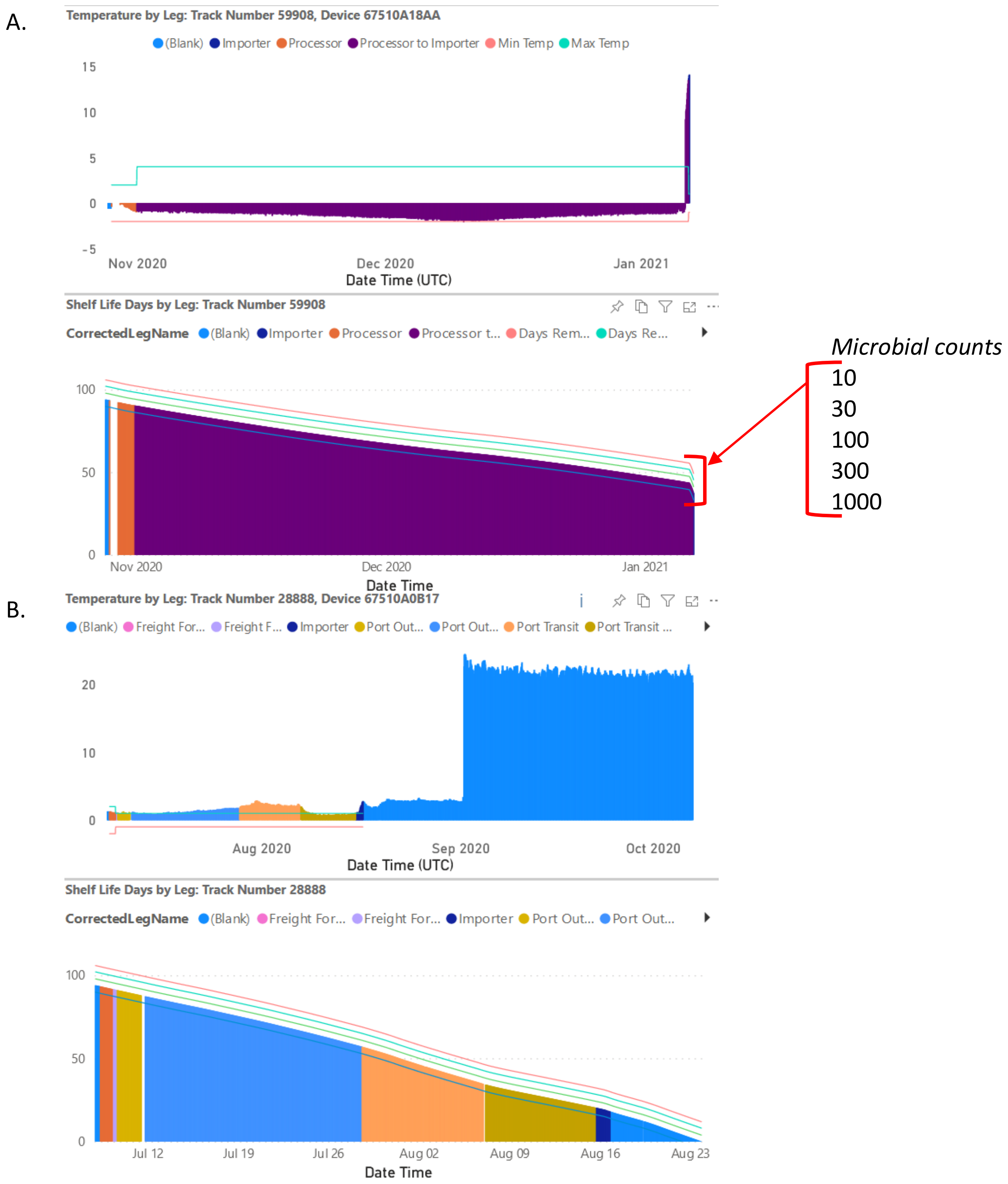
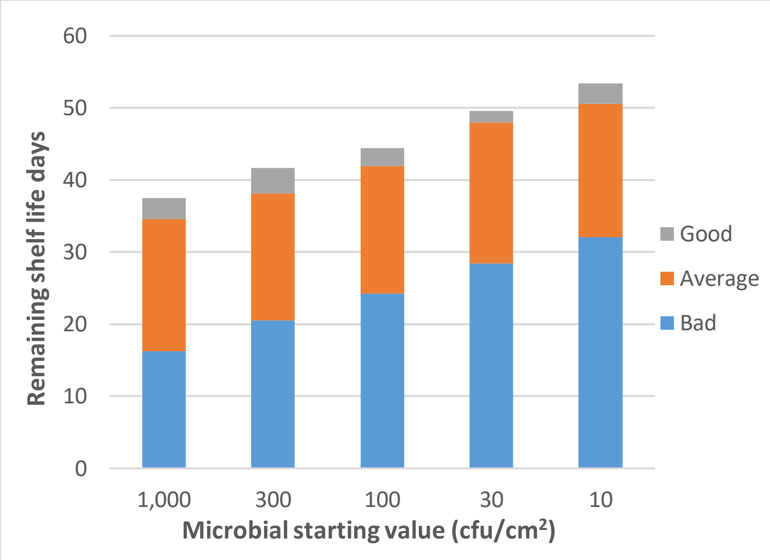


Figure 20. Good (A) and bad (B) beef tracks to the Middle East with variable microbial counts



The 'bad' beef track to South Korea as seen in Figure 20 (B) highlights how temperature can have a significant impact on shelf life as shelf life is rapidly lost due to an increase in temperature. This trend occurs regardless of starting microbial value. This correlation of bad temperature control resulting in greater loss of shelf life regardless of microbial value can also be seen in Figure 21.

Figure 21. The impact of microbial starting values on remaining shelf life days on lamb tracks to the Middle East with varying temperature control.



5 Conclusion

This project successfully used the Escavox solution and integrated shelf life model at scale to identify crucial variability points within the cold supply chain for Australian red meat exports from abattoir through to importer.

1000 cartons were tracked over 800 different supply chain journeys to 22 countries by sea or air.

The MLA shelf-life prediction model was applied to the data obtained from Escavox trackers to calculate each carton's shelf life. The differences and value for repeat instances of tracks on the same routes, and between different routes were assessed. Differences between sea and air tracks to the same destination were also analysed.

To allow all tracks to be compared regardless of journey time, destination or channel, a new measurement was created – the rate of shelf life lost per day. This allowed legs of the journey to be compared and legs or locations with significant rate of shelf life loss to be investigated.

The comparison of temperature, duration, shelf life lost and rate of shelf life loss of each of these tracks has allowed a number of conclusions to be drawn (see key findings).

The data obtained throughout this study was able to identify several supply chain operations changes to improve shelf life and red meat quality that the study participants implemented.

5.3 Key findings

Overall

- There is significant variability in temperature control and shelf life outcomes in all export routes. There are no consistently 'good' routes or shipment modes.
- Long shelf life can be achieved but is not guaranteed. Tracking the temperature and location of product in red meat cold chains is fundamental to identifying and fixing issues in the supply chain. Ideally all routes should be tracked but at a minimum problem routes should be audited.
- Visibility of the cold chain identifies problems and allows change to be implemented that extends shelf life.
- A critical point in maintaining the export cold chain is the initial cooling of product to -1°C.
- Sharing data with other supply chain participants directly improves the temperature control and operational decisions which positively impact shelf life, quality and brand.

Case study

- Supplying data to prove sea freight suitability for US shipments resulted in 7x higher volume sales, reduced freight costs of $3.82/kg and enhanced brand reputation
- Changes in abattoir and reefer temperatures resulted in a shelf life saving of 50 days.
- Shelf life results validate capability to meet Middle East shelf life requirement changes

- The variability in primal temperature prior to leaving the processor directly impacts the maintained temperature of the rest of the journey. Primals held at -1°C prior to dispatch are able to maintain sub zero temperatures this maintaining rate of shelf life loss at <1 day
- Sharing cold chain data with Food Service customers and communicating benefits of lowering storage temperatures was positively received and a 1°C reduction in storage temp resulted in a 25 day increase in shelf life
  - Singapore food service customer made changes to storage temp of cold room based on shelf life days lost per day metric. From this data set now clearly understands the opportunity cost of the additional shelf life days of chilled product which far outweighs the additional energy costs to store product

Variability in Supply Chain

- All channels show high levels of variability in temperature storage, handover points and duration. Air freight is significantly more variable than sea freight. Temperature impacts product shelf life at any point in the supply chain and the more variable the temperature, the higher the rate of shelf life loss.
- Average Beef Temperatures to importer were 0.7 +- 1°C, average lamb temperatures were -0.1 +- 1°C
- Sea freight exports are able to achieve the same shelf life outcomes as air freight exports.
- Product moved by air has a much more variable rate of shelf life loss compared to product moved by sea. On average, product moved by sea loses 1.6 days of shelf life for every day in transit, whereas by air this is 3.6 days of shelf life.
- The variability of primal temperature prior to leaving the processor directly impacts the maintained temperature of the rest of the journey. Primals held at -1C prior to dispatch are able to maintain sub zero temperatures this maintaining rate of shelf life loss at <1 day. It can take 72 hours to chill a primal from 3°C to -1.5°C and live visibility in plant is crucial to ensure temperature is optimal prior to dispatch
- The correlation between temperature control and shelf life loss is stronger than the correlation between journey time and shelf life loss
- Moving and storing primals consistently at or below -0.5°C results in a rate of shelf life loss per day of <1. Moving or storing primals consistently above -0.5°C results means shelf life is lost at a faster rate than 1 day per day of journey time.

Microbiological count

- Product temperature has a greater impact on shelf life loss and remaining shelf life days than starting microbial counts.
- Improved cold chain performance and handling of product from all parties in the chain can deliver optimum shelf life of product to importing customers.

5.4 Benefits to industry

Participants were able to **increase sales volume** by providing assurance of the temperature control and shelf life impact on their product. This also **solidified their brand as a quality and consistent product**.

With the global trend of improving processing facilities and therefore micro counts, Australia's advantage in this area will be eroded. The combination of low starting micro and monitoring and maintaining cold chain of -0.5C is significant in **maintaining the Australian competitive advantage** in chilled red meat.

Monitoring and maintaining cold chains enables a choice between air and sea freight as viable option for all export markets leading to a **reduction of freight costs** when moving from air freight to sea freight for selected markets that were not previously accessible. These cost reductions can be passed onto customers and may result in **further increased sales volumes.**

Sharing data with participants in the supply chain encourages open conversations and **builds relationships.**

Cold chain monitoring has directly enabled the establishment of **new food safety protocols** for Middle East bound red meat exports, extending from 70 to 90 shelf-life days for chilled lamb and 70 to 120 shelf-life days for chilled beef.

A **reduction in rejections** due to better and consistent temperature control could lead to **reduced insurance premiums**. One load with appropriately precooled and stored meat in a sea shipment was held up off shore for 3 weeks due to a Covid quarantine but with limited impact to the product. No claim was made by the importer or customer.

In summary, the benefits to industry are:

- Increased sales volumes
- Brand protection and enhancement
- Reduction in freight costs
- Reduced rejections
- Builds relationships between supply chain partners
- Reduced insurance premiums
- Maintaining Australian Competitive advantage
- Supports more beneficial market access protocols

6 Future research and recommendations

Future recommendations:

- Tracking temperature and location of red meat export shipments has multiple benefits. Exporters can minimise product damage by understanding and monitoring their cold chains,
- Implement an industry' shelf life lost per day' metric as an easy comparison of how well a cold chain is performing. This moves attention away from speed or temperature to a combination of both in one simple metric
- Ability to enter a processor specific starting micro to give a more accurate shelf life. A low micro count will help with longer shelf life although cold chain control is more important.
- Sharing data allows importers to make informed decision on stock rotation and management of promotion sales, managing a QIQO (quality in, quality out) rather than FIFO.
- Integration of the platform temp alerts, shelf life calculation into industry QA platforms, Logistic platforms and operational platforms.
- Integration of live on sea data into one end to end system to allow live downstream impacts and decisions to be assessed in real time.
- Using proof of consistent optimal temperature performance and limited rejections to reduce insurance premiums.

Future Research:

- Carton level tracking – ability to assign a shelf life down to a carton level
- Quantify the impact of managing a QIQO rather than FIFO allocation system

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8 Appendix

The following Appendices relate to individual country analysis of shelf life. For each grouping of tracks, the following areas are analysed and discussed.

1. good, average and bad tracks
2. percentage of tracks meeting the 90 days shelf life requirement (beef) or 70 days shelf life requirement (lamb)

Examples of these tracks are also given and analysed.

8.3 United States of America

Beef and lamb supply chains to both the West and East Coasts of the United States of America (USA) were analysed in this study (Figure 22). Typically, both air and sea freight are used to transport Australian red meat exports to the USA. There are major differences in how product is handled when using air freight vs. sea freight.

Air freight is a popular method of transport when exporting Australian red meat to the US. However, air freight has been particularly impacted with the ongoing COVID 19 pandemic.

Figure 22. Beef and lamb cold chain export routes to the USA

Of the 48 beef tracks analysed, 59% of sea freight and 100% of air freight fell short of achieving 90 days at 2°C (average -4.2±10.9 and -28.1±6.0 respectively). Of the 16 lamb tracks analysed, 81%fell short of achieving 70 days at 2°C (average -10.8±13.6). All 16 lamb racks were sea freight, no air freight shipments were tracked in the study (Table 7)

Table 7. Percentage of beef and lamb tracks falling short of achieving 90 days (beef) or 70 days (lamb) shelf life. This has been further divided into sea or air freight.

	Sea Freight		**Air Freight**	
Country	% of **Beef** sea freight **not** meeting 90 days when held at 2°C	% of **Lamb** sea freight **not** meeting 70 days when held at 2°C	% of **Beef** air freight **not** meeting 90 days when held at 2°C	% of **Lamb** air freight **not** meeting 70 days when held at 2C
USA	59%	81%	100%	N/A

8.3.1 Sea Freight of Beef to the US

A sample of beef sea freight exports were broken into good, average, and bad tracks to highlight crucial variable points when exporting to the USA (Table 8).

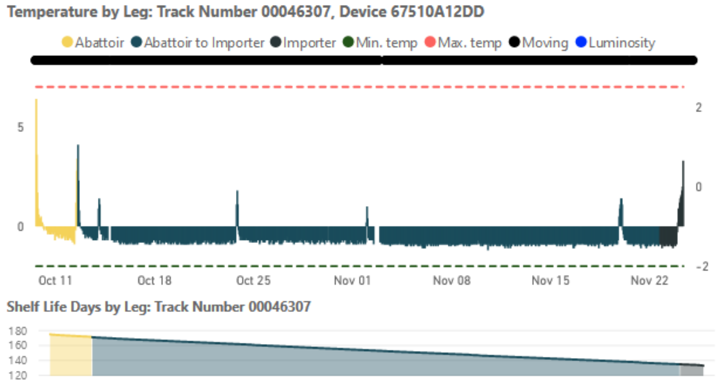
Table 8. A breakdown of shelf life for beef tracks exported to the USA.

Beef Tracks				**Predicted Shelf Life at various temperatures**		
	Total days to importer	*Actual Average Temp (°C)*	*Average Shelf-life lost per day*	Total shelf-life days at -0.5°C	Total shelf-life days at 2°C	Achieving 90 days at 2°C
Good	44.8	-0.9	0.5	172.4	92.7	2.7
	44.9	-0.7	0.9	179.0	95.3	5.3
	46.4	-0.4	1.1	169.9	92.8	2.8
	63.5	-0.3	1.1	169.2	103.2	13.2
	42.0	-0.3	1.2	165.6	88.4	-1.6
Average	47.8	0.0	1.2	164.2	91.5	1.5
	63.8	0.2	1.4	149.2	95.9	5.9
	49.5	0.6	1.8	149.1	86.9	-3.1
	48.3	1.2	1.9	132.7	80.0	-10.0
	51.6	0.7	1.9	132.7	82.0	-8.0
Bad	40.8	1.2	2.0	133.0	75.4	-14.6
	36.7	2.4	2.6	113.5	65.6	-24.4
	45.4	2.5	2.6	93.8	63.6	-26.4
	42.0	2.1	2.9	107.2	66.5	-23.5
	40.6	2.4	3.1	111.8	67.3	-22.7
Average of all USA sea tracks	51.2	0.8	1.8	143.5	85.8	-4.2

An example of good sea freight can be seen in Figure 23 (A). In this track, temperature was well maintained over the transport of the beef at a temperature of -0.8±0.3. Peaks seen through the transport journey can be correlated to arrival or departure from ports. Additionally, careful temperature control at the abattoir (average temperature of 0.0±1.2) has helped this track maintain consistency over the entire export supply chain.

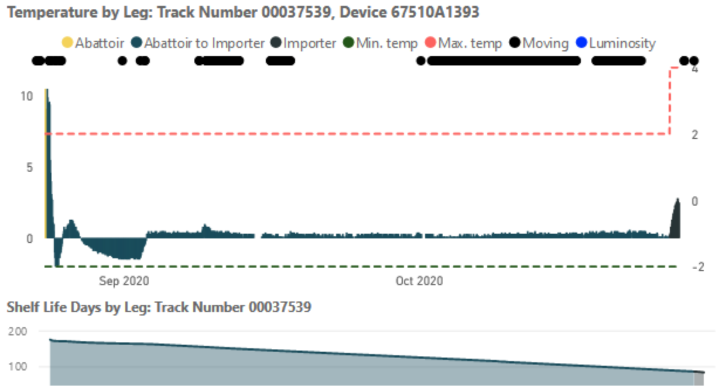
Figure 23. Examples of good (A), average (B), and bad(c) beef tracks sea freighted to the USA.

A.



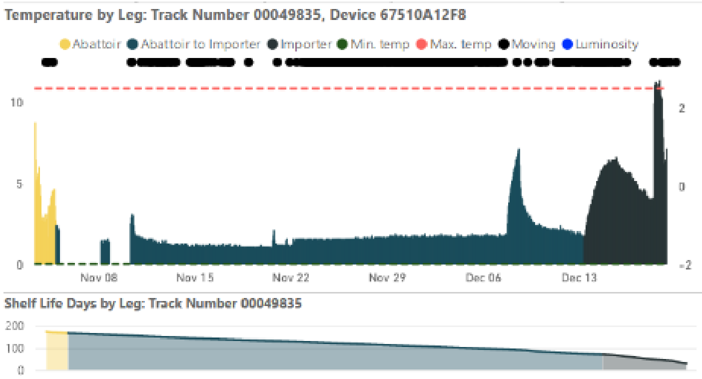
Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	0.0	1.2	-2.0--2.5	94%	2.9	1.3
Abattoir to Importer	-0.8	0.3	-2.0--2.5	100%	41.9	0.9
Importer	-0.3	1.1	-2.0--2.5	97%	1.6	1.2
Total	**-0.7**	**0.5**	**-2.0--2.5**	**99%**	**46.5**	**0.9**

B.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	9.0	0.9	-2.0--2.0	0%	0.1	
Abattoir to Importer	0.2	0.9	-2.0--2.0	99%	63.8	1.4
Importer	1.9	0.8	-2.0--4.0	100%	1.0	2.6
Total	**0.2**	**1.0**	**-2.0--2.0**	**99%**	**65.0**	**1.4**

C.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	4.0	1.5	-2.0--2.5	7%	1.5	4.4
Abattoir to Importer	1.7	0.8	-2.0--2.5	94%	39.0	2.5
Importer	5.7	2.0	-2.0--2.5	3%	6.0	6.9
Total	**2.4**	**1.8**	**-2.0--2.5**	**78%**	**46.6**	**3.1**

Figure 23 (B) highlights a commonly observed variable in export meat tracks. At the start of the transit leg, a curve can be observed reaching a minimum of -2.0°C and a maximum of 1.3°C. This flip can affect meat quality at the start of the track and highlights the importance of maintaining temperature during transport from the abattoir or processor. In this case, it appears the product was loaded at a high temperature (average 9°C+0.9°C) and this phenomenon was the result of rapid cooling within the freight truck.

An example of a bad track to the USA can be seen in Figure 23 (C). In this case, the temperature of the beef was held at a temperature high enough to result in a rapid loss of shelf life. The abattoir did not cool the product enough before it left for transport (average temperature 4.0°C±1.5°C, shelf life lost per day was 4.4 days). Once the beef started the export cold chain journey, the average temperature was 1.7°C±0.8°C and the average shelf life lost per day was 2.5 days. A peak reaching a maximum of 7.1°C can be observed towards the end of the track showing when the product was unloaded at port. The importer also held the product at quite a high temperature (average 5.7°C±2.0°C) resulting in a shelf life loss per day of 6.9 days.

This last track highlights three weak points in the cold chain of sea shipments:

1. cooling at abattoir
2. the importance of maintaining a low temperature during prolonged transport routes
3. the importance of good communication on temperature control with the importer

8.3.2 Air freight of beef to the US

A sample of beef air freight exports were broken into good, average, and bad tracks to highlight crucial variable points when exporting by air to the USA (Table 9).

Table 9. Air freight tracks to the US

Beef Tracks				**Predicted Shelf Life at various temperatures**			
	Total days to importer	*Total shelf-life days at -0.5°C*	*Total shelf-life days at 2°C*	Achieving 90 days at 2°C (days of shelf life remaining)	Actual Average Temp (°C)	Average Shelf-life lost per day	West Coast (WC) or East Coast (EC)
Good	8.5	168.3	68.5	-21.5	0.4	1.6	WC
	9.7	148.2	61.7	-28.3	0.1	1.6	EC
	8.7	166.5	68.0	-22.0	1.0	1.9	WC
Average	9.7	149.7	83.3	-27.7	1.7	**2.7**	EC
	6.9	146.8	59.4	-30.6	3.6	4.4	WC
	9.7	154.8	64.2	-25.8	2.3	3.0	WC
Bad	20.8	93.8	48.2	-41.8	2.7	4.9	EC
	8.2	118.7	49.7	-40.3	3.6	**5.2**	EC
	7.6	125.5	51.9	-38.1	4.9	6.4	WC
Average of all USA air tracks	9.8	147.3	*62.8*	-28.5	2.4	3.4	

Analysis of these tracks demonstrated a large variance of shelf life remaining on Australian red meat exports airfreighted to US importers. On average, air freight exports to the US took 9.8 days from processor to importer. The average temperature for these exports was 2.4°C and the exported beef would on average, lose 3.4 days of shelf life per day.

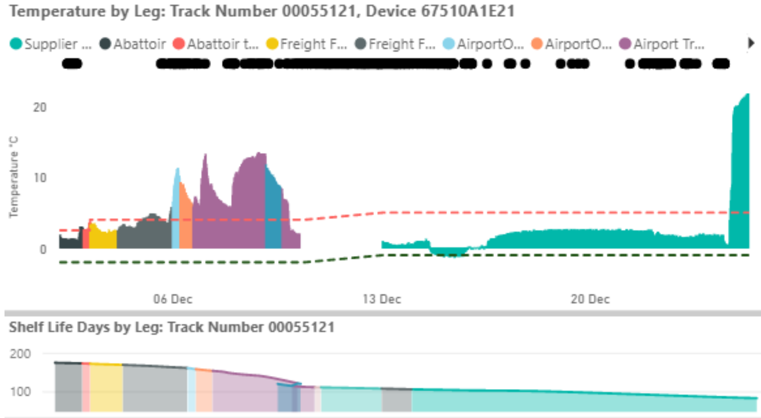
As outlined below, the number of handling points and transit airports/transfer flights can have an impact upon the variation of temperature within the legs of the journey. The best-case arrival of shelf life remaining was 156 days (Figure 26, A) while the worst arrival had 110 days of shelf life remaining (Figure 24, A) as discussed below. The remaining shelf life days were obtained from the Escavox platform.

Three examples of tracks with lower shelf life (bad tracks) are highlighted inTable 9. The full tracks can be viewed in Figure 24. The first track (Figure 24, A) had numerous stops on its export journey (abattoir, freight forwarder, outbound airport, two transit airports and inbound airport) before arriving at the importer and being tracked deeper into the supply chain to arrival at the supplier distribution center. This demonstrates how complicated Australian export red meat airfreight can be, and how many handling points there are in the cold chain journey.

In this case, the highest average temperature during the export journey occurred between airport transits (average temperature of 11.3°C$\pm$1.3) resulting in an average of 14.4 days shelf life days lost per day. By the time the product arrived at the importer, 110 days of shelf life remained. A similar trend can be observed for Figure 24 (B). For this track, multiple peaks can be seen as the product either arrived or departed from a know location (e.g. inbound airport). This track fared slightly better as it was able to achieve 124 days of shelf life remaining upon arrival to the importer.

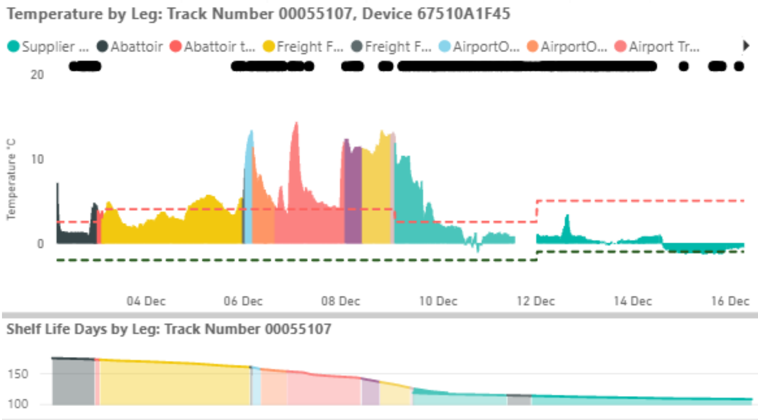
Figure 24. Bad air freight to the US

A.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Supplier DC	2.3	3.9	-1.0--5.0	91%	12.3	1.9
Abattoir	1.5	0.6	-2.0--2.5	85%	0.8	2.2
Abattoir to Freight ...	2.7	0.3	-2.0--2.5	38%	0.2	3.4
Freight Forwarder	2.6	0.4	-2.0--4.0	100%	0.9	3.2
Freight Forwarder t...	3.8	0.8	-2.0--4.0	60%	1.8	4.4
Total	**3.4**	**4.1**	**-1.5--4.3**	**74%**	**23.1**	**4.0**

B.

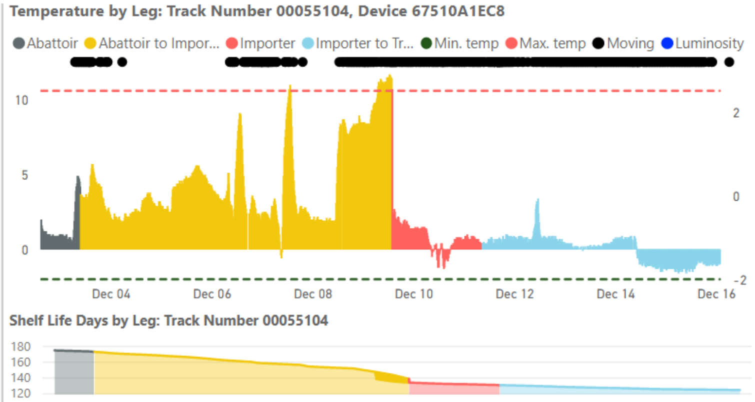


Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Supplier DC	0.0	0.9	-1.0--5.0	83%	4.2	1.3
Abattoir	2.0	1.4	-2.0--2.5	77%	0.8	2.5
Abattoir to Freight ...	3.5	0.2	-2.0--2.5	0%	0.1	4.1
Freight Forwarder	3.5	1.1	-2.0--4.0	68%	2.9	4.2
Freight Forwarder t...	6.6	1.4	-2.0--4.0	0%	0.0	8.6
Total	**3.2**	**3.7**	**-1.7--3.9**	**60%**	**14.1**	**4.7**

Finding the balance when it comes to temperature control using air freight, can be difficult as seen in these average tracks below. Figure 25 (A) and (B) show how even having good temperature control before and after arrival at importer, a high average temperature during air transport (4.5°C$\pm$2.7°C and 3.3°C$\pm$1.9°C respectively) can result in a rapid loss of shelf life days (5.7 days and 4.0 days lost per day of transit respectively).

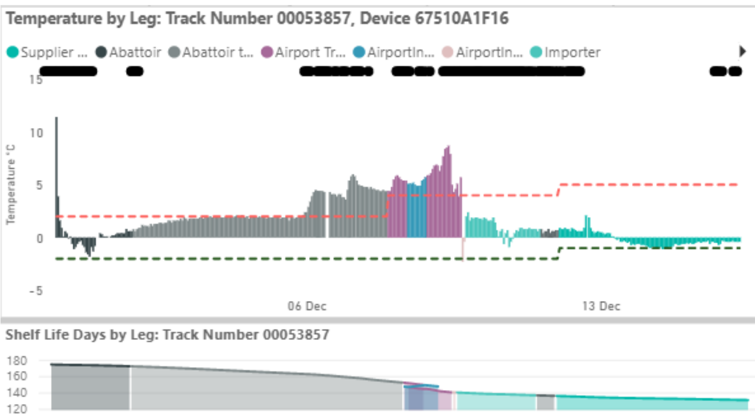
Figure 25. Average air freight to the US

A.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	1.4	1.2	-2.0--2.5	87%	0.8	2.4
Abattoir to Importer	4.5	2.7	-2.0--2.5	30%	6.8	5.7
Importer	0.8	1.1	-2.0--2.5	99%	2.4	3.3
Importer to Track E...	0.0	0.9	-2.0--2.5	99%	4.7	1.3
Total	**2.3**	**2.9**	**-2.0--2.5**	**66%**	**14.0**	**3.6**

B.

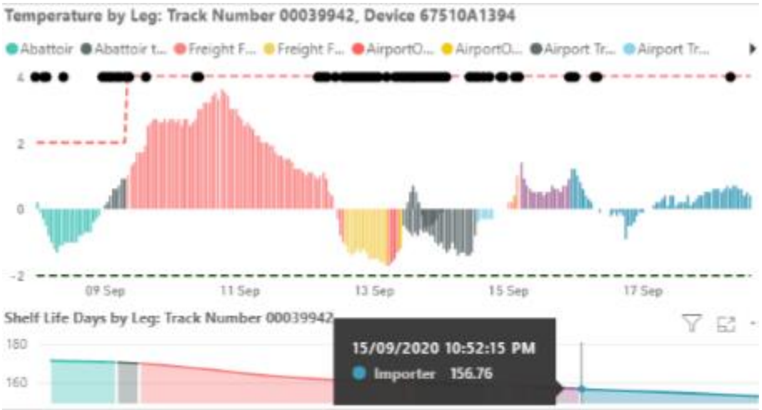


Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Supplier DC	-0.2	0.7	-1.0--5.0	95%	4.3	1.2
Abattoir	0.3	1.9	-2.0--2.0	95%	1.8	1.2
Abattoir to Airport ...	2.6	1.4	-2.0--2.0	65%	6.0	3.3
Airport Transit to Ai...	5.3	0.5	-2.0--4.0	0%	0.4	6.3
Airport Transit to Ai...	6.4	1.3	-2.0--4.0	5%	0.8	7.7
Total	**1.7**	**2.2**	**-1.7--3.3**	**74%**	**16.3**	**2.7**

Two of the best performing air freight tracks can be seen in Figure 26. The first track (Figure 26, A) demonstrates how good temperature control management can be obtained even when there are transit airport stops. The highest average temperature was at the freight forwarder where the temperature reached a maximum of 3.6°C (average temperature was 2.0°C±1.0°C). This maintenance of low temperature throughout the rest of the export journey resulted in an average of 1.6 days of shelf life lost per day of export, and 156 days of remaining shelf life upon arrival at the importer.

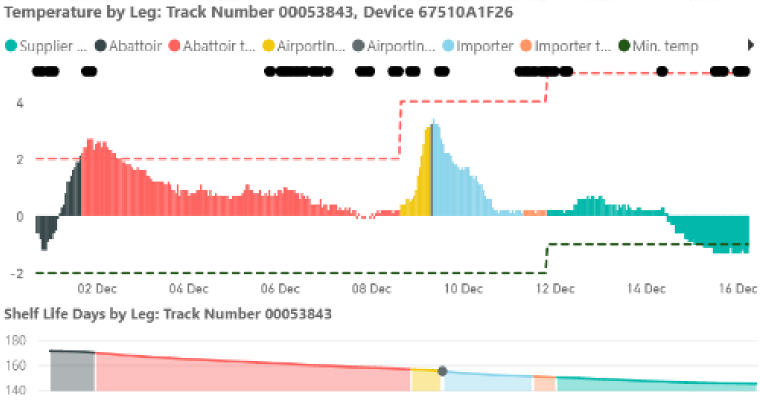
Figure 26. Good air freight to the US

A.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	-0.7	0.4	-2.0--2.0	100%	1.0	0.9
Abattoir to Freight ...	0.6	0.3	-2.0--2.0	100%	0.3	1.5
Freight Forwarder	2.0	1.0	-2.0--4.0	100%	3.2	2.8
Freight Forwarder t...	-1.4	0.2	-2.0--4.0	100%	0.6	0.6
AirportOutbound	-1.5	0.1	-2.0--4.0	100%	0.1	0.6
Total	**0.4**	**1.3**	**-2.0--3.8**	**100%**	**11.2**	**1.6**

B.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Supplier DC	-0.5	0.7	-1.0--5.0	67%	4.4	1.2
Abattoir	0.2	1.1	-2.0--2.0	96%	1.0	1.5
Abattoir to Airportl...	0.9	0.7	-2.0--2.0	89%	6.9	1.9
AirportInbound	1.4	1.0	-2.0--4.0	100%	0.6	2.3
AirportInbound to I...	3.2	0.0	-2.0--4.0	100%	0.0	0.0
Total	**0.3**	**1.1**	**-1.6--3.7**	**82%**	**15.6**	**1.7**

Overall, although air freight is a faster method of export than sea freight, we ultimately disproved our hypothesis that airfreight would have higher remaining shelf life due to the significantly quicker transit time. Instead, lack of quality temperature control when exporting with airfreight results in faster rates of shelf life lost. This is a particularly relevant finding for the export meat industry as we observe that due to COVID 19, there are limitations around the number of flights to the US West Coast, along with huge increases in air freight costs.

8.3.3 Lamb Tracks

A sample of lamb sea freight exports were broken into good, average and bad to highlight crucial variable points when exporting to the USA (Table 10).

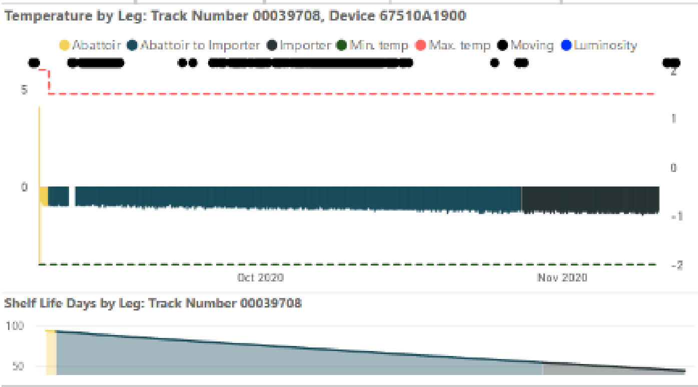
Table 10. A breakdown of shelf life for lamb tracks exported to the USA.

Lamb Tracks				**Predicted Shelf Life at various temperatures**		
	Total days to importer	*Actual Average Temp (°C)*	*Average Shelf-life lost per day*	Total shelf-life days at -0.5°C	Total shelf-life days at 2°C	Days remaining if achieving 70 days at 2°C
Good	50	*-1.1*	0.8	104.5	74.4	4.4
	53.6	*-0.4*	0.9	96	72.6	2.6
	61.7	*0.4*	1.0	90.6	74.6	4.6
	46.8	*-0.6*	0.9	95	68.4	-1.6
	46.8	*-0.5*	1.0	93.4	67.6	-2.4
Average	60.8	*0.6*	1.3	74.9	67.1	-2.9
	52.1	*-0.2*	1.0	85.5	67	-3.0
	45.6	*-0.5*	1.1	90.5	65.7	-4.3
	28.5	*-0.7*	0.9	96.2	58.8	-11.2
	45.3	*0.6*	1.5	72.2	57.3	-12.7
Bad	20.4	*0.5*	1.4	84.8	49.2	-20.8
	45.7	*1.3*	0.4	49.4	47.4	-22.6
	35.2	*-1.3*	0.7	47.2	40.6	-29.4
	38.4	*1.4*	1.7	38.7	38.5	-31.5
	31.7	*2.5*	1.9	31.7	31.7	-38.3
Average of USA lamb tracks	44.6	0.1	1.1	77.3	59.2	-10.8

Examples of good, average and bad lamb exports to the USA can be seen in Figure 27. The major difference for these tracks as compared to beef tracks exported to the USA is temperature. A good track has well maintained temperature over the entire journey resulting in the average shelf life loss per day of less than 1 day lost (e.g. 0.8 days lost Figure 27, A). Average tracks tend to experience some temperature fluctuations (Figure 27, B), while bad tracks have consistently higher temperatures (Figure 27, C).

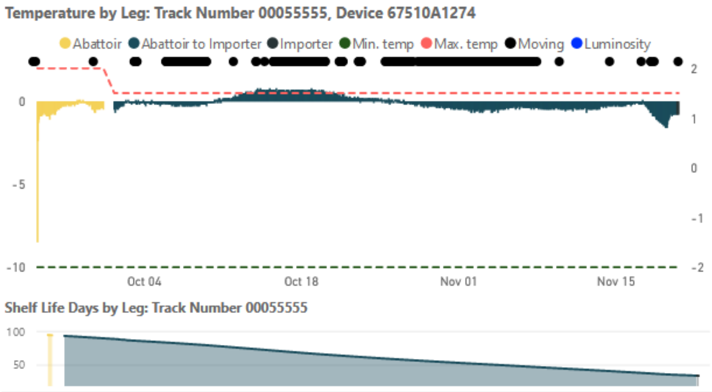
Figure 27. An example of a good lamb track (A), an average lamb track (B) and a bad lamb track (C) sea freighted to the USA.

A.



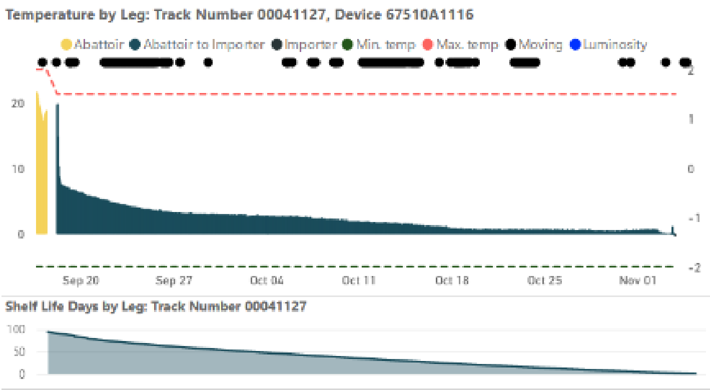
Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	-0.8	1.2	-2.0--2.0	92%	1.0	0.8
Abattoir to Importer	-1.1	0.1	-2.0--1.5	100%	49.0	0.8
Importer	-1.3	0.1	-2.0--1.5	100%	14.2	0.7
Total	**-1.1**	**0.2**	**-2.0--1.5**	**100%**	**64.2**	**0.8**

B.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	-0.5	0.8	-2.0--2.0	99%	5.9	0.1
Abattoir to Importer	-0.1	0.4	-2.0--1.5	100%	50.8	1.2
Importer	-0.8	0.0	-2.0--1.5	100%	0.1	0.9
Total	**-0.2**	**0.5**	**-2.0--1.6**	**100%**	**57.8**	**1.0**

C.

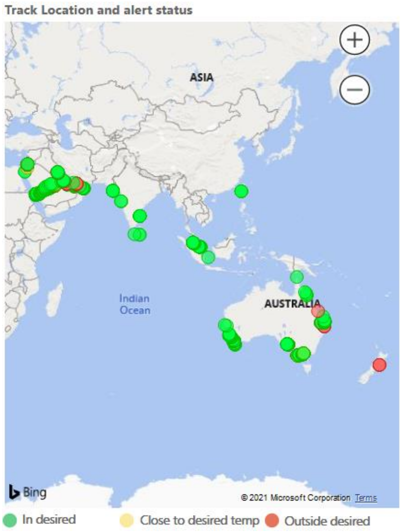


Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	18.9	1.5	-2.0--2.0	0%	0.8	
Abattoir to Importer	2.3	1.9	-2.0--1.5	43%	47.3	2.0
Importer	-0.4	0.0	-2.0--1.5	100%	0.0	0.0
Total	**2.5**	**2.9**	**-2.0--1.5**	**42%**	**48.8**	**1.9**

8.4 Middle East

Beef and lamb supply chains to the Middle East were analysed in this study (Figure 28) Airfreight during the period of this study was heavily restricted due to the emergence of the COVID-19 virus. Therefore, the majority of tracks analysed were sea freight.

Figure 28. Beef and lamb cold chain export routes to the Middle East



Of the 49 beef tracks analysed (Table 11), 65.3% fell short of achieving 90 days at 2°C (average achieved -4.6+11.7 days shelf life). Of the 62 lamb tracks analysed, 66.1% fell short of achieving 70 days at 2°C (average -5.6±12.9 days shelf life).

Table 11. Percentage of beef and lamb tracks falling short of achieving 90 days (beef) or 70 days (lamb) shelf life.

	Beef	Lamb
Country	% of **Beef not** meeting 90 days when held at 2°C	% of **Lamb not** meeting 70 days when held at 2°C
Middle East	65.3	66.1

8.4.1 Beef Tracks

A sample of the 49 beef sea freight exports were broken into good, average and bad to highlight crucial variable points when exporting to the Middle East (Table 12).

From this selection, we can examine an example of a good beef track in Figure 29 (A). This track highlights how keeping product at a low temperature can help slow the rate of shelf life lost per day. This particular track was kept at -1.4°C over a 50.6 day journey resulting in an average shelf life loss of only 0.6 days lost per day of dwell time.

In contrast, Figure 29 (B) demonstrates how a potentially good track can become an average track. In this case, multiple temperature spikes (max 2.0°C for 24 hours) can affect overall rate of shelf life loss. These spikes happened whilst in transit to the Middle East and may be due to the container being powered off while at port or transit port. More regular spikes can sometimes be attributed to a reefer defrosting cycle.

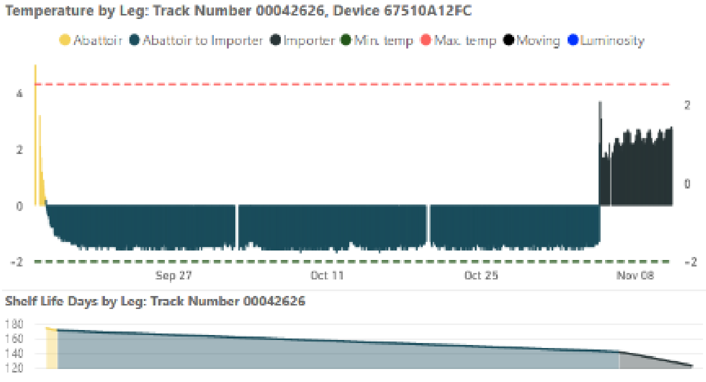
Table 12. A breakdown of total shelf life for beef tracks exported to the Middle East.

Beef Tracks				**Predicted Shelf Life at various temperatures**		
	Total days to importer	*Actual Average Temp (°C)*	*Average Shelf-life lost per day*	Total shelf-life days at -0.5°C	Total shelf-life days at 2°C	Days remaining if achieving 90 days at 2°C
Good	51.6	*-1.0*	0.9	193.7	105.0	15.0
	47.1	*-1.2*	0.9	185.9	99.3	9.3
	45.3	*-0.9*	0.8	181.9	96.6	6.6
	37.1	*-0.4*	0.9	178.1	90.1	0.1
	41.1	*0.3*	1.0	173.2	90.7	0.7
Average	51.9	*0.1*	1.5	163.1	93.6	3.6
	39.7	*0.0*	1.3	162.3	85.7	-4.3
	31.4	*0.2*	1.5	159.9	79.7	-10.3
	43.1	*0.2*	1.4	156.5	85.7	-4.3
	24.6	*0.4*	1.6	154.7	73.5	-16.5
Bad	51.1	*0.5*	1.7	146.7	87.0	-3.0
	36.4	*1.3*	2.2	145.3	77.3	-12.7
	31.7	*1.3*	2.2	139.5	72.2	-17.8
	45.3	*1.8*	2.5	113.9	71.0	-19.0
	70.8	*1.0*	2.0	105.6	83.9	-6.1
Average of Middle East beef tracks	43.4	0.7	1.5	152.9	84.5	-5.5

Figure 29 (C) shows a track that was held at an average temperature of 1.5°C for over 44.3 days of transit. While this temperature was held consistently, the higher temperature resulted in an average of 2.3 days of shelf life lost per day in transit. When this track arrived, it only had 33.8 days of shelf life remaining. Compared to the example of a good beef track which had 123.2 days of shelf life remaining on arrival, this track highlights the importance of small temperature differences on rate of shelf life loss.

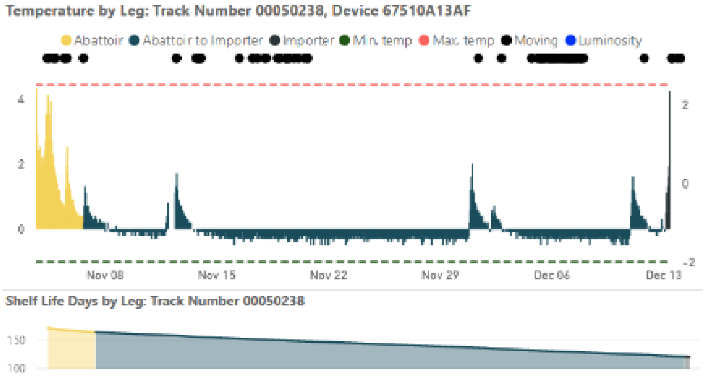
Figure 29. An example of a good (A), average (B) and bad (C) beef track to the Middle East

A.



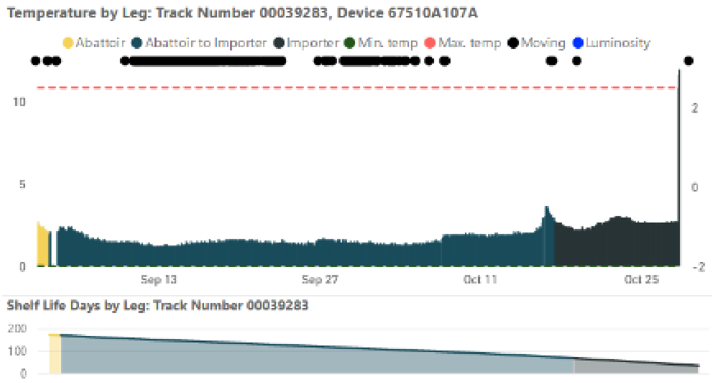
Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	1.3	1.3	-2.0--2.5	87%	1.0	2.6
Abattoir to Importer	-1.4	0.2	-2.0--2.5	100%	50.6	0.6
Importer	2.2	0.3	-2.0--2.5	77%	6.5	2.9
Total	**-1.0**	**1.2**	**-2.0--2.5**	**97%**	**58.2**	**0.9**

B.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	1.6	1.1	-2.0--2.5	83%	2.9	2.4
Abattoir to Importer	-0.1	0.3	-2.0--2.5	100%	36.7	1.2
Importer	1.5	1.2	-2.0--2.5	86%	0.3	2.6
Total	**0.0**	**0.6**	**-2.0--2.5**	**99%**	**39.9**	**1.3**

C.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	2.2	0.2	-2.0--2.5	96%	1.0	2.9
Abattoir to Importer	1.5	0.4	-2.0--2.5	98%	44.3	2.3
Importer	2.6	1.0	-2.0--2.5	36%	10.8	3.1
Total	**1.8**	**0.7**	**-2.0--2.5**	**86%**	**56.1**	**2.5**

8.4.2 Lamb Tracks

A sample of the 62 lamb tracks were taken and broken down into good, average and bad tracks (Table 13).

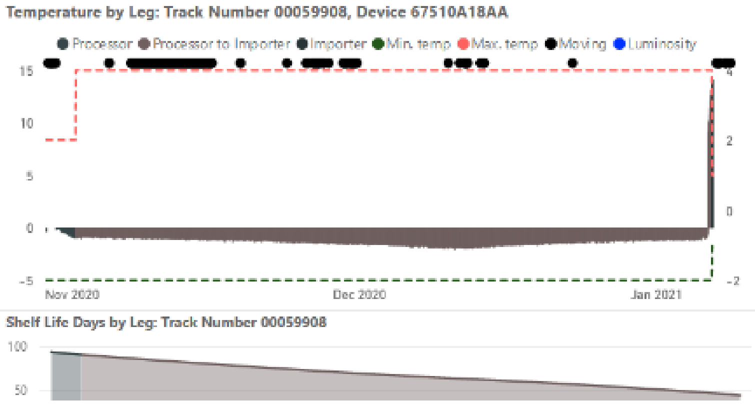
Table 13. A breakdown of shelf life for lamb tracks exported to the Middle East.

Lamb Tracks				**Predicted Shelf Life at various temperatures**		
	Total days to importer	*Actual Average Temp (°C)*	*Average Shelf-life lost per day*	Total shelf-life days at -0.5°C	Total shelf-life days at 2°C	Achieving 70 days at 2°C
Good	69.4	-1.2	0.7	113.5	89.2	19.2
	44.5	-1.0	0.9	110.0	73.8	3.8
	46.2	-0.9	0.8	103.6	71.9	1.9
	25.1	-1.1	0.8	103.4	60.1	-9.9
	48.8	-0.9	0.8	101.6	72.4	2.4
Average	36.9	-0.6	1.0	97.4	63.9	-6.1
	30.9	-0.2	1.1	95.6	59.8	-10.2
	21.2	-1.4	0.5	94.6	54.0	-16.0
	57.2	-0.5	1.0	93.1	73.2	3.2
	51.0	-0.4	1.0	92.7	69.7	-0.3
Bad	4.3	1.6	2.1	90.0	42.6	-27.4
	60.1	0.2	1.3	84.0	70.8	0.8
	54.2	0.2	1.3	79.6	65.5	-4.5
	45.1	1.6	1.4	75.0	58.5	-11.5
	38.3	1.4	1.9	59.4	47.8	-22.2
Average of Middle East lamb tracks	38.2	-0.2	1.1	92.8	62.6	-6.9

Figure 30 demonstrates a good, average and bad lamb track to the Middle east. As can be observed, these tracks follow the same trend as the beef tracks outlined above. The good track (Figure 30, A) held transport temperature at -1.3°C over the course of the 66.8 day journey to the Middle East. The resulted in only 0.7 days shelf life lost per day of transit. In contrast, the bad track (Figure 30, B) had an average temperature of 1.4°C over the 37.3 day transit to the Middle East. This higher temperature, although still within ideal temperature bands resulted in 1.9 days of shelf life lost per day of transit, resulting in a greatly reduced final shelf life.

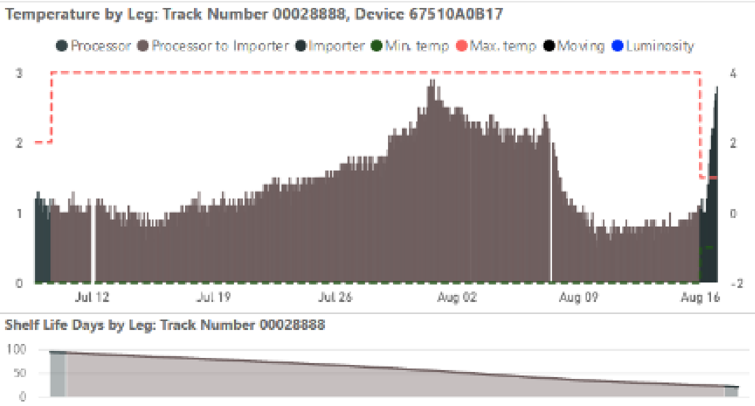
Figure 30. An example of a good (A), average and bad (B) lamb track to the Middle East

A.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Processor	-0.5	0.3	-2.0--2.0	100%	3.0	1.0
Processor to Import...	-1.3	1.0	-2.0--4.0	99%	66.8	0.7
Importer	13.9	0.2	-1.0--1.0	0%	0.1	
Total	**-1.2**	**1.2**	**-2.0--3.9**	**99%**	**70.0**	**0.7**

B.

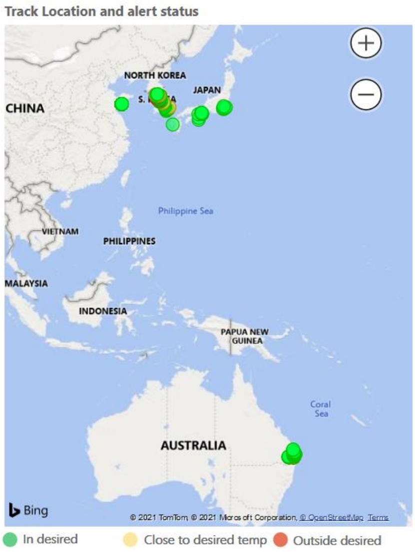


Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Processor	1.1	0.1	-2.0--2.0	100%	0.9	1.8
Processor to Import...	1.4	0.6	-2.0--4.0	100%	37.3	1.9
Importer	1.5	0.6	-1.0--1.0	38%	1.1	1.2
Total	**1.4**	**0.6**	**-2.0--3.9**	**98%**	**39.4**	**1.9**

8.5 South Korea

Several supply chains to South Korea were analysed (Figure 31).

Figure 31. Beef cold chain export routes to South Korea



Of the 72 beef tracks analysed (Table 14), 88.16% fell short of the 90 days shelf life (average -11.4±9.8 days shelf life). Tracks where beef was held below -0.5°C for much of the journey returned better shelf life lost per day averages (Table 15) than those held above as predicted by the SLA model.

Table 14. Percentage of beef and lamb tracks falling short of achieving 90 days (beef) or 70 days (lamb) shelf life.

	Beef	Lamb
Country	% of **Beef not** meeting 90 days when held at 2°C	% of **Lamb not** meeting 70 days when held at 2°C
Middle East	88.16	N/A

Figure 32 (A) highlights how maintaining a track at a low temperature (-1.0±0.7) can result in less shelf life loss per day. Over 31.5 days of transport to South Korea, this track only lost an average of 0.8 days per day of dwell time. The peak (5°C) near the end of the journey is commonly observed when unloading product at the South Korean port of arrival. Once the product arrived at importer, the temperature increased to an average of 0.7°C and the shelf life lost per day increased to

This example of an average beef track to South Korea (, B) demonstrates a correction in temperature. This beef was loaded at a higher temperature (Av. 2.2°C±2.4 °C) resulting in a high rate of shelf life loss (3.6 days of shelf life lost per dwell day). The peak at the start of the transit leg can be attributed to loading from the abattoir, followed by a smaller peak at loading onto the ship transport. Throughout the supply chain, the beef is systematically cooled resulting in an average temperate of 0.5°C with a peak of 5°C and a minimum temp of -1.5°C.

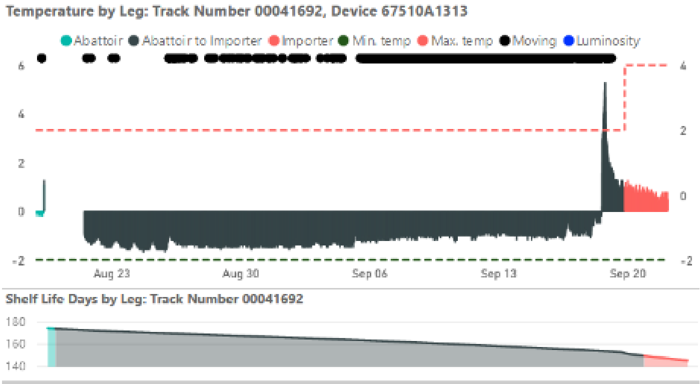
Table 15. A breakdown of shelf life for beef tracks exported to South Korea.

Beef Tracks				**Predicted Shelf Life at various temperatures**		
	Total days to importer	*Average Temp (°C)*	*Average shelf-life lost per day*	Total shelf-life days at -0.5°C	Total shelf-life days at 2°C	Achieving 90 days at 2°C
Good	32.0	-0.9	0.9	180.9	87.9	-2.1
	27.3	-0.2	1.3	179.7	84.6	-5.4
	29.5	-0.4	1.1	180.1	86.1	-3.9
	26.6	-0.2	1.2	172.4	81.4	-8.6
	45.1	0.8	1.5	157.0	87.1	-2.9
Average	25.9	0.2	1.5	161.2	76.8	-13.2
	29.1	0.9	1.9	161.4	78.8	-11.2
	28.3	0.9	1.9	153.8	75.4	-14.6
	14.9	0.8	1.8	172.7	74.2	-15.8
	28.1	0.7	1.8	153.1	75.1	-14.9
Bad	21.0	1.1	2.0	158.0	72.5	-17.5
	27.9	1.3	2.2	151.1	74.2	-15.8
	27.8	1.8	2.5	130.1	66.2	-23.8
	27.4	1.7	2.4	127.1	64.8	-25.2
	37.9	0.3	3.2	89.7	57.4	-32.6
Average of South Korea beef tracks	31.9	0.6	1.7	158.0	79.3	-10.7

The track in Figure 32 (C) shows a particularly bad sea freight track to South Korea. There were several variability points along this particular supply chain. The initial transport from abattoir to port outbound had an average temperature of 1.7°C$\pm$0.9°C. This product remained at the outbound port for 7 days and was well maintained at 0.4°C$\pm$0.3°C. However, major issues occurred while travelling to the transit port of Qingdao, China. Temperature reached a maximum of 17.3°C with an average of 4.1°C$\pm$5.0 for this leg of the journey. This temperature spike resulted in a loss of 6.3 shelf life days per day of dwell time for a 14.3 day period. Whilst in the transit port, the beef was cooled to -5.3 in preparation for arrival at port inbound.

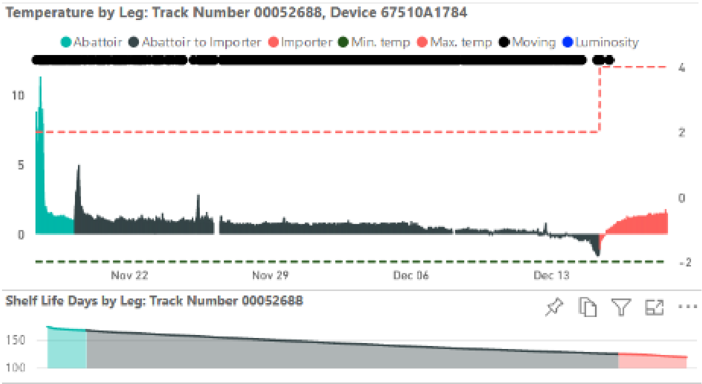
Figure 32. Examples of a good (A), average(B) and bad (c) tracks to South Korea

A.



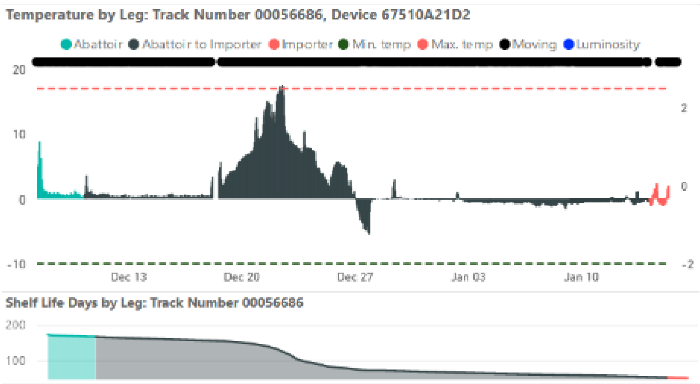
Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	0.0	0.2	-2.0--2.0	100%	0.4	1.2
Abattoir to Importer	-1.0	0.7	-2.0--2.0	99%	31.5	0.8
Importer	0.7	0.2	-2.0--4.0	100%	2.3	1.7
Total	**-0.9**	**0.8**	**-2.0--2.1**	**99%**	**34.3**	**0.9**

B.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	2.2	2.4	-2.0--2.0	84%	1.9	3.6
Abattoir to Importer	0.5	0.5	-2.0--2.0	99%	26.1	1.6
Importer	0.9	0.5	-2.0--4.0	100%	3.3	1.9
Total	**0.7**	**0.9**	**-2.0--2.2**	**98%**	**31.4**	**1.8**

C.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	1.1	1.6	-2.0--2.5	92%	2.9	2.2
Abattoir to Importer	0.3	2.4	-2.0--2.5	92%	34.9	3.3
Importer	0.1	1.0	-2.0--2.5	100%	1.2	1.4
Total	**0.3**	**2.3**	**-2.0--2.5**	**93%**	**39.1**	**3.2**

8.6 Canada

Beef and lamb supply chains Canada were analysed in this study (Figure 33). As only a small number of beef tracks were exported to Canada via air freight, and no beef tracks were exported to Canada by sea freight in this study, this analysis mainly concentrated on lamb cold chain exports.

Figure 33. Beef and Lamb cold chain export routes to Canada

Of the 29 lamb tracks analysed (Table 16), 34% of exported lamb fell short of achieving 70 days at 2°C (an average 5.3±13.8 days shelf life). This lower percentage indicates that the cold supply chain to the US is well established, however, there is still room for improvement of certain crucial variability points in this supply chain. To assist in analysing these points of variability, lamb tracks to Canada were broken down into good, average and bad tracks (Table 17).

Table 16. Percentage of beef and lamb tracks falling short of achieving 90 days (beef) or 70 days (lamb) shelf life.

	Beef	Lamb
Country	% of **Beef not** meeting 90 days when held at 2°C	% of **Lamb not** meeting 70 days when held at 2°C
Middle East	N/A	34

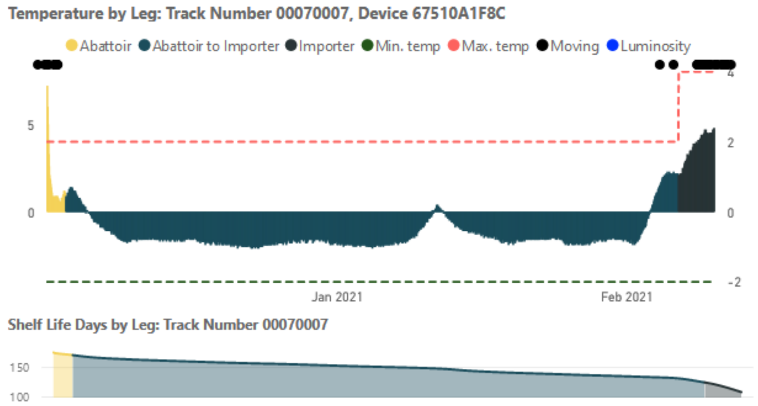
Examples of good, average and bad lamb exports to Canada can be seen in Figure 34. The major points of variability that can be highlighted by these two tracks are, initial transport from abattoir temperatures, maintaining good communications with importers and temperature monitoring of reefers during export. Figure 34 (A) is an example of a good track to Canada, however, it could have been even better. While temperature was well maintained during the journey (average temperature -1.3°C+0.9°C) resulting in a low average shelf life loss per day (0.7), the abattoir and importer temperatures accelerated the shelf life lost per day, leading to a higher overall average of 0.9 days lost per day. The bad track seen in Figure 34 (B), demonstrates a warming reefer. This gradual warming accelerates the shelf life lost and can have a large impact on final shelf life days. In this case, Escavox was able to generate an alert indicating a warming load which was then acted upon by one of the participants of this study.

Table 17. A breakdown of shelf life for lamb tracks exported to Canada.

Lamb Tracks				**Predicted Shelf Life at various temperatures**		
	Total days to importer	*Actual Average Temp (°C)*	*Average Shelf-life lost per day*	Total shelf-life days at -0.5°C	Total shelf-life days at 2°C	Achieving 70 days at 2°C
Good	72.0	*-0.9*	0.9	99.9	84.5	14.5
	60.4	*0.0*	0.7	107.8	81.6	11.6
	62.3	*-2.2*	0.6	106.5	82.1	12.1
	59.4	*-1.2*	0.8	96.4	76.0	6.0
	60.7	*-0.9*	0.9	101.8	79.1	9.1
Average	61.1	*-0.5*	0.9	98.7	77.9	7.9
	58.5	*-0.7*	0.9	98.8	76.5	6.5
	61.8	*-0.5*	1.0	92.5	75.5	5.5
	37.5	*-0.9*	0.8	100.0	65.5	-4.5
	52.7	*-0.4*	1.0	92.6	70.5	0.5
Bad	59.5	*-0.3*	1.1	90.7	73.5	3.5
	51.2	*0.0*	1.2	88.9	68.1	-1.9
	49.4	*0.1*	1.3	89.2	67.2	-2.8
	47.1	*0.5*	1.4	73.9	59.1	-10.9
	17.2	*-0.5*	1.0	94.3	51.7	-18.3
Average of Canada lamb tracks	54.0	-0.5	1.0	94.3	72.0	2.0

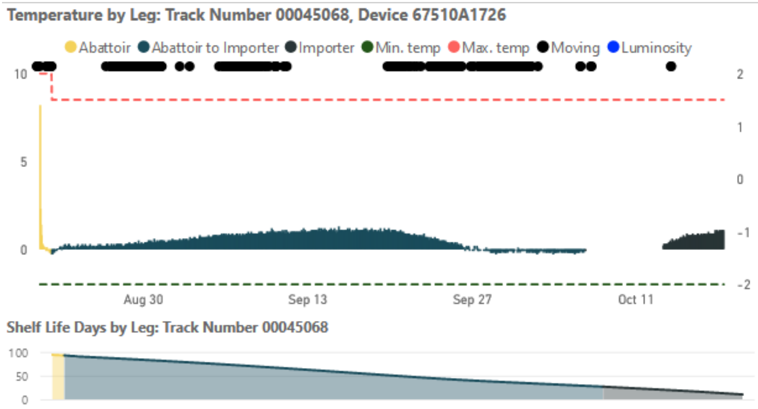
Figure 34. An example of a good (A) and bad (B) lamb track to Canada

A.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	1.4	1.4	-2.0--2.0	85%	2.0	2.2
Abattoir to Importer	-1.3	0.9	-2.0--2.0	97%	66.2	0.7
Importer	3.7	0.8	-2.0--4.0	57%	3.8	4.3
Total	**-0.9**	**1.5**	**-2.0--2.1**	**95%**	**72.0**	**0.9**

B.

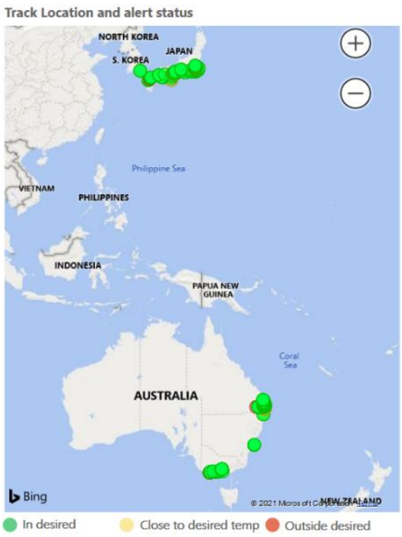


Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	0.5	1.7	-2.0--2.0	92%	1.0	1.3
Abattoir to Importer	0.5	0.4	-2.0--1.5	100%	46.0	1.4
Importer	0.7	0.2	-2.0--1.5	100%	11.8	1.4
Total	**0.5**	**0.5**	**-2.0--1.5**	**100%**	**58.8**	**1.4**

8.7 Japan

Beef and lamb supply chains to Japan were analysed in this study (Figure 35). As only a small proportion of these tracks were lamb, the focus of this analysis will be on beef.

Figure 35. Beef and lamb cold chain export routes to Japan



Of the 55 beef tracks analysed (Table 18), 96.36% fell short of achieving 90 days at 2°C (average -13.6±6.8 shelf life days and -28.1±6.0 shelf life days respectively). Of the 11 lamb tracks analysed, 100% fell short of achieving 70 days at 2°C (average -12.1±6.6 shelf life days).

Table 18. Percentage of beef and lamb tracks falling short of achieving 90 days (beef) or 70 days (lamb) shelf life.

	Beef	Lamb
Country	% of **Beef not** meeting 90 days when held at 2°C	% of **Lamb not** meeting 70 days when held at 2°C
Middle East	96.36	100

8.7.1 Beef Tracks

A sample of the 55 beef sea freight exports were broken into good, average, and bad to highlight crucial variable points when exporting to Japan (Table 19).

Table 19. A breakdown of shelf life for beef tracks exported to Japan.

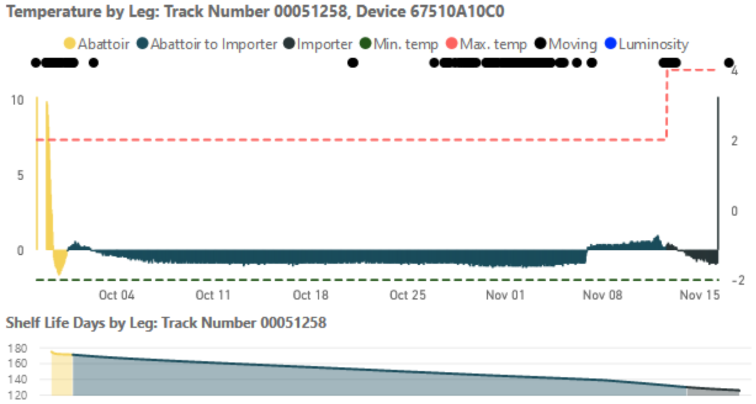
Beef Tracks				**Predicted Shelf Life at various temperatures**		
	Total days to importer	*Actual Average Temp (°C)*	*Average Shelf-life lost per day*	Total shelf-life days at -0.5°C	Total shelf-life days at 2°C	*Achieving 90 days at 2°C*
Good	44.7	*-0.5*	1.0	174.1	93.3	3.3
	33.0	*-0.6*	1.0	176.8	87.0	-3.0
	31.8	*-0.1*	1.2	169.1	83.4	-6.6
	27.6	*0.0*	1.3	166.4	79.7	-10.3
	20.1	*0.2*	1.4	165.4	74.7	-15.3
Average	18.5	*0.4*	1.6	162.0	72.4	-17.6
	29.0	*0.6*	1.7	161.1	78.6	-11.4
	21.1	*0.8*	1.7	158.5	72.7	-17.3
	27.2	*0.7*	1.7	156.0	75.6	-14.4
	25.7	*0.8*	1.5	155.1	74.3	-15.7
Bad	18.1	*1.2*	2.0	152.0	68.4	-21.6
	17.0	*1.5*	2.3	151.4	67.5	-22.5
	18.5	*1.2*	2.3	151.0	68.2	-21.8
	25.9	*1.5*	2.3	133.4	66.3	-23.7
	34.5	*1.8*	2.6	120.2	66.7	-23.3
Average of Japan beef tracks	27.1	0.5	1.7	158.0	76.3	-13.7

Examining export supply chains to Japan we found that, on average, exports to Japan were shipped or air freighted at a higher temperature compared to temperatures for other countries. While other export destinations were able to achieve less that 1 day of shelf life lost per day, this was the lowest rate of shelf life lost able to be achieved for beef tracks to Japan. This trend may be due to the shorter journey from Australia to Japan.

Temperature is still an important factor when exporting beef to Japan. As observed in Figure 36, a good track may be able to achieve an extra 45 days of shelf life due to transit at a lower temperature. In this case, a good track (Figure 36, A) was held at -0.6°C for 43.2 days of transport resulting in 1.0 days of shelf life lost er day of transport. The bad track, as seen in Figure 36 (B), was held at an average of 1.8°C over a 33.7 day journey to Japan, meaning 2.6 days of shelf life were lost per day of transport. In addition, the bad track had several temperature spikes related to arrival or departures from ports.

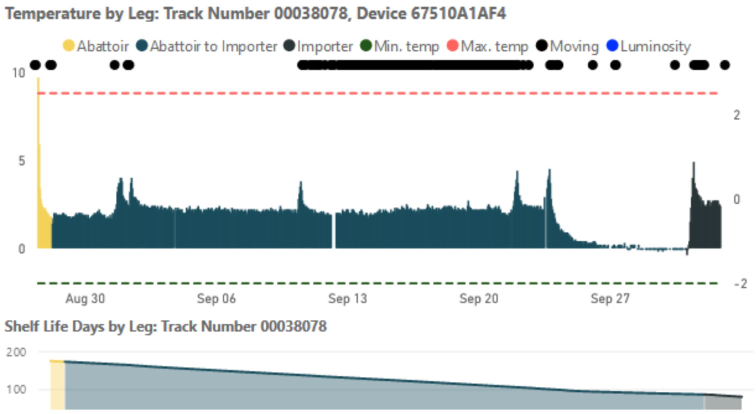
Figure 36. An example of a good (A) and bad (B) beef track to Japan

A.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	1.3	3.8	-2.0--2.0	70%	2.2	1.7
Abattoir to Importer	-0.6	0.5	-2.0--2.0	100%	43.2	1.0
Importer	-0.3	1.2	-2.0--4.0	99%	3.7	1.2
Total	**-0.5**	**1.0**	**-2.0--2.2**	**99%**	**49.1**	**1.0**

B.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	2.8	1.9	-2.0--2.5	78%	0.7	3.2
Abattoir to Importer	1.8	0.9	-2.0--2.5	94%	33.7	2.6
Importer	2.3	1.2	-2.0--2.5	47%	1.9	3.1
Total	**1.8**	**1.0**	**-2.0--2.5**	**91%**	**36.4**	**2.6**

8.7.2 Lamb Tracks

A sample of the 11 lamb sea freight exports were broken into good, average, and bad to highlight crucial variable points when exporting to Japan (Table 20). Unlike beef exports, good lamb exports to Japan are held at lower temperatures.

Table 20. A breakdown of shelf life for lamb tracks exported to Japan.

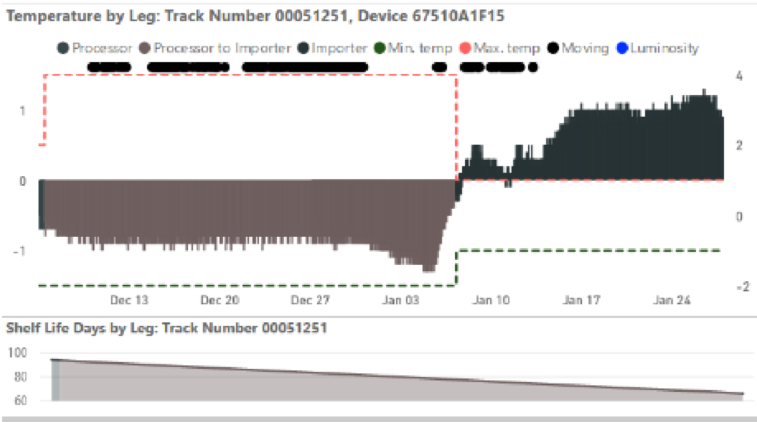
Lamb Tracks				**Predicted Shelf Life at various temperatures**		
	Total days to importer	*Average Temp (°C)*	*Average Shelf-life lost per day*	Total shelf-life days at -0.5°C	Total shelf-life days at -2°C	Achieving 70 days at 2°C
Good	32.4	-0.2	0.5	98.0	61.7	-8.3
	32.6	-1.1	0.8	101.2	63.3	-6.7
Average	21.7	-0.3	1.1	95.9	54.9	-15.1
	32.2	0.0	1.2	87.8	57.0	-13.0
Bad	34.7	0.4	1.4	76.2	53.2	-16.8
	34.7	1.4	1.9	78.1	54.1	-15.9
Average of Japan lamb tracks	33.0	-0.1	1.1	92.0	59.4	-10.6

Figure 37 (A), highlights how keeping a low temperature for the duration of a track can result in a low loss of shelf life. The good track started at the processor at a temperature of -0.6°C resulting in only 1 day of shelf life loss per day. Once the lamb started its export journey, the average temperature was kept at -0.8°C±0.2°C and thus the average rate of shelf life lost per day was reduced to 0.9 days lost per day of transport. The importer also maintained a relatively low temperature (average 0.7°C) aiding in reducing shelf life loss.

In contrast, the bad lamb track (Figure 37, B) had a higher temperature at the processor start (0.5°C) and had an average temperature of 1.4°C during the 28.5 day journey to Japan. This resulted in an average shelf life loss of 1.9 days per day of transit.

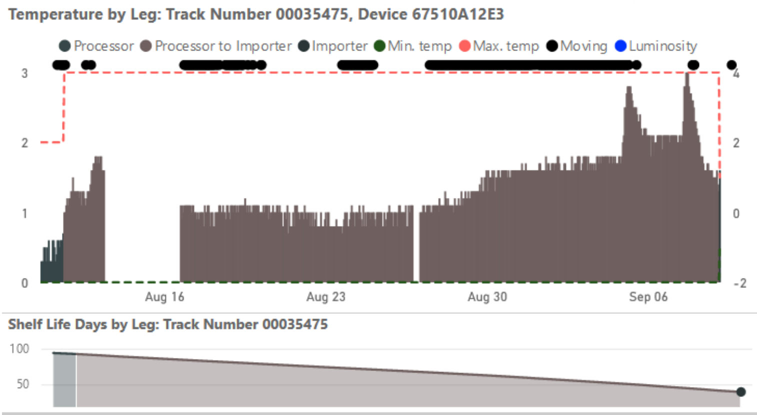
Figure 37. An example of a good (A) and bad (B) lamb track to Japan

A.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Processor	-0.6	0.1	-2.0--2.0	100%	0.4	1.0
Processor to Import...	-0.8	0.2	-2.0--4.0	100%	31.9	0.9
Importer	0.7	0.4	-1.0--1.0	91%	20.6	0.0
Total	**-0.2**	**0.8**	**-1.6--2.7**	**96%**	**53.0**	**0.5**

B.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Processor	0.5	0.1	-2.0--2.0	100%	1.0	1.4
Processor to Import...	1.4	0.5	-2.0--4.0	100%	28.5	1.9
Importer	1.6	0.0	-1.0--1.0	0%	0.0	0.0
Total	**1.4**	**0.5**	**-2.0--3.9**	**100%**	**29.5**	**1.9**

8.8 Taiwan

Beef supply chains to Taiwan were analysed in this study (Figure 38). Taiwan is a relatively small part of Australia's red meat export, and as such, only 16 beef tracks were recorded.

Figure 38. Beef cold chain export routes to Taiwan

Of the 16 beef tracks analysed (Table 21), 87.5% fell short of achieving 90 days at 2°C (average -10.5$\pm$7.54 shelf life days). A selection of these tracks were broken into good, average, and bad to highlight crucial variable points when exporting to Taiwan (Table 22).

Table 21. Percentage of beef and lamb tracks falling short of achieving 90 days (beef) or 70 days (lamb) shelf life.

	Beef	Lamb
Country	% of **Beef not** meeting 90 days when held at 2°C	% of **Lamb not** meeting 70 days when held at 2°C
Middle East	87.5	N/A

Beef exports to Taiwan also highlighted the variability in temperature exports experience. An example of a good track can be seen in Figure 39 (A). Although this was a good beef track, it could have been better. The export cold chain in transit had an average temperature of -0.6°C, however, the numerous spikes in temperature resulted in a standard deviation of 1.3°C and pushed the rate of shelf life loss up to 1 day of shelf life lost per day of transit.

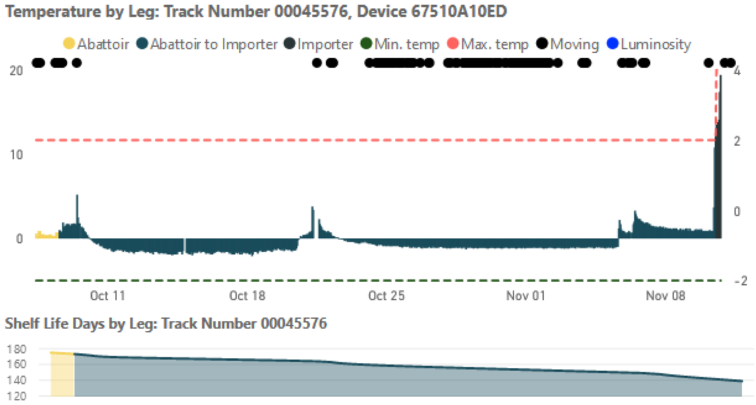
Figure 39 (B) is an example of a bad beef track to Taiwan. This track exhibits some of the features previously highlighted in bad beef tracks. For example, the initial temperature of the beef at the abattoir was and average 3.1°C resulting 4 days of shelf life lost per day at the abattoir. The beef was initially transported at this high temperature and was eventually cooled to -0.3°C resulting in an average temperature of 1.6°C for the length of the export journey. This variation in temperature for the 23.7 days of transit resulted in an average of 2.5 days of shelf life lost per day of transit.

Table 22. A breakdown of shelf life for beef tracks exported to Taiwan.

Beef Tracks				**Predicted Shelf Life at various temperatures**		
	Total days to importer	***Average Temp (°C)***	***Average Shelf-life lost per day***	**Total shelf-life days at -0.5°C**	**Total shelf-life days at -2°C**	**Achieving 90 days at 2°C**
Good	34.1	-0.4	1.0	172.2	86.0	-4.0
	63.6	0.3	1.6	137.3	91.3	1.3
	32.6	0.8	1.2	168.8	83.8	-6.2
	18.1	-0.1	1.2	168.6	74.6	-15.4
	30.4	1.4	1.5	176.1	85.1	-4.9
Average	29.9	0.4	1.5	158.9	78.4	-11.6
	26.2	0.5	1.7	167.1	79.2	-10.8
	31.3	0.3	1.8	165.3	81.6	-8.4
	29.8	0.7	1.9	169.0	82.1	-7.9
	30.5	0.9	2.0	167.6	82.0	-8.0
Bad	20.2	1.2	2.0	153.7	70.3	-19.7
	51.1	1.6	2.1	117.6	76.1	-13.9
	18.3	1.3	2.3	168.2	74.6	-15.4
	30.8	0.7	2.3	132.5	69.0	-21.0
	26.0	1.8	2.6	132.4	66.0	-24.0
Average of Taiwan beef tracks	31.5	0.8	1.8	157.0	78.7	-11.3

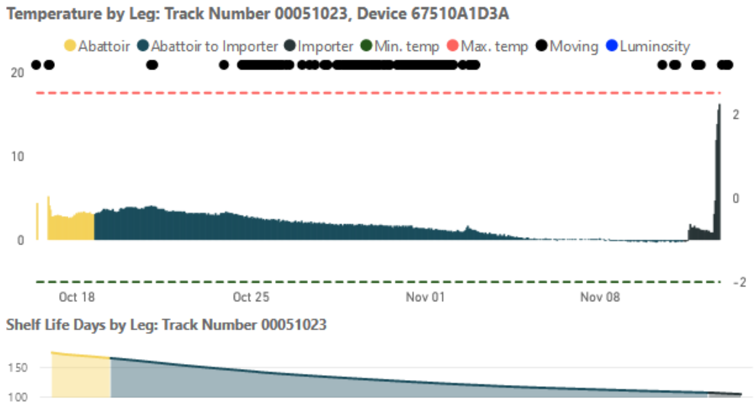
Figure 39. An example of a good (A) and bad (B) beef track to Taiwan

A.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	0.5	0.2	-2.0--2.0	100%	1.1	1.6
Abattoir to Importer	-0.6	1.3	-2.0--2.0	98%	33.0	1.0
Importer	15.3	2.3	-2.0--4.0	0%	0.2	
Total	**-0.4**	**1.9**	**-2.0--2.0**	**97%**	**34.5**	**1.0**

B.



Leg Name	Avg. Temp. (C)	Std. Dev. of Temp. (C)	Desired Temp Ranges	Time in Temp (%)	Dwell (days)	Shelf Life Lost per Day
Abattoir	3.1	0.5	-2.0--2.5	0%	2.3	4.0
Abattoir to Importer	1.6	1.3	-2.0--2.5	72%	23.7	2.5
Importer	2.7	4.3	-2.0--2.5	83%	1.4	1.9
Total	**1.8**	**1.7**	**-2.0--2.5**	**68%**	**27.5**	**2.6**