final report

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Prediction of shelf life and cold chain monitoring of Red Meat in Australian domestic supply chain

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Executive summary

The pilot aims to define the commercial benefit for Australian Red Meat industry from continuous cold chain monitoring of red meat from abattoir through the supply chain to retail shelf. The method is to track 100 journeys across abattoir to processor, processor to store and DC to store. Apply MLA shelf life algorithm to determine impact of temperature control and duration from abattoir.

The shelf life algorithm predicts the end of shelf-life for beef and lamb based on unacceptable, strong odour on opening the vacuum pack. The tool has undergone a significant validation process using data from company shelf life trials. It works for both beef and lamb vacuumed products.

The model used total viable count (TVC) Micro as a starting count and based on the temperature history and future storage temp, it can predict shelf life remaining. The usual observation from all the shelf life trials are micro count reaches maximum and dependent on storage temp, a few weeks after organoleptic deterioration can be observed.

Some key findings of the pilot:

- Shelf life on Vacuum Skin Pack (VSP) is considerably longer than current industry 'Best Before' dates. There is a high risk of product being marked down/destroyed too quickly.
- Initial areas of concern for shelf life and food safety impacts are secondary freight for regional Australia.
- DC temperature checks on arrival give limited value in determining safety or shelf life considerations.

The project has measured the current supply chain of red meat to through a variety of domestic retail supply chains. As a result this has provided the opportunity to draw a number of conclusions:

- There is considerable variability of the cold supply chain from abbatoir to processor and processor to retail store, which affects the potential shelf life of meat at retail shelf and in the home.
- The potential of VSP red meat has additional shelf life days not considered under the current 'best before dates' system.
- Results show that there are challenges in maintaining the cold chain in regional long haul transport legs which impacts the shelf life potential of the product.
- There are a number of areas where further research / validation would assist the industry to maximise the opportunities from shelf life model work already completed.

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1 Background

The length of time that food remains edible and nutritious depends on multiple variables including temperature, moisture, and other factors that affect the growth rates of organisms that cause spoilage.

The journey of chilled red meat from abattoir to a retail store is generally between 9 and 90 days in Australia and change of ownership occurs on average between 2 and 5 times.

Fresh food supply chains are inherently complicated, fragmented and diverse. Reasons for this are:

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

Escavox is a fresh food knowledge business which provides services to assist businesses monitor and optimise the performance of their cold chains. These services provide automated, independent objective data on supply chain performance by tracking the movement of the product and the conditions to which it is exposed as it travels from farm to retail shelf. This primary data is then analysed against product specific criteria and the resulting information provides the necessary insights that allows supply chain operators to make better informed decisions about the optimal management of product and investments in the supply chain. The automated end-to-end services and level of integrated insight into supply chain and product performance that Escavox provides has not been previously accessible to the commercial fresh food industry.

Current approaches to supply chain tracking, i.e. monitoring temperatures and time in the supply chain, have provided inadequate outcomes when trying to view the end-to-end supply chain. Solutions are often compromised because of the need to trade-off cost, data accuracy, infrastructure requirements, frequency of upload and data interpretation. Cheaper single use 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 therefore lacks meaningful insights (e.g. raw CSV). Additionally, nearly all of the current approaches require manual input by unskilled workers and store persons and therefore can be highly prone to misuse and erroneous data.

In contrast to existing approaches, the Escavox approach is capture data from the complete chain whilst minimise touchpoints with the hardware and automate as many functions as possible in the collection and interpretation of data. . This results in:

- reduced reliance on people to facilitate the data collection process, reducing costs and errors,
- 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 .

MLA previous shelf life model projects focused on the scientific element of the model to ensure the model was accurate in its microbial growth predictions. As the current supply chain landscape is becomes more complex as consumers have higher expectations of quality of food they consume, this provided the opportunity to present information in a more useful and meaningful way. It is possible to show the variance and complexity of supply chains that support Australian retail meat trade by mapping the time and temperature that product is in the suppy chain and applying that to the shelf life model to understand real use case output and the commercial opportunities available to industry in the adoption of the the MLA shelf life model for 'best before dates'.

This trial is to investigate and potentially demonstrate the commercial viability of continual cold chain monitoring of red meat supply chain to identify issues, improvequality and increase ROI from abattoir to processor and processor to retail shelf.

MLA remains committed to showcasing supply chain decisions based on data capture and analysis to inform strategies to grow demand and production decisions.

2 Project objectives

2.1 Objectives

- Investigate the current supply chain of red meat to through a variety of domestic retail supply chains.
- EscaVox platform to identify the variability of the cold supply chain from abbatoir to processor and processor to retail store. Pilot data will be used to calculate shelf life of each carton tracked, then compared to current shelf life expiration date to assess differences and value.
- 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.
- Provide real use case of MLA shelf life algorithm with view to validate investment in a larger pilot to validate findings.
- EscaVox to deliver two final reports; one confidential version for parties involved. The second Final Report will be dispersed for the meat industry with the stakeholders sign off.

3 Methodology

3.1 Supply Chain Tracking

The following approach was applied in this project

1) Escavox supply chain tracking and analytics technology was used to monitor and interpret performance of supply chain and product in selected red meat supply chains.
2) MLA's shelf life algorithm (see figure 1) was incorporated to predict shelf life during the supply chain from live sensor data collected to calculate shelf life once tracked product has arrived at the store. Devices were installed into cartons of meat to track from abattoir to processor. Devices were again installed into retail ready packs from processor to retail store.
3) A sample of the multitude of suppy chains that form the the Australian retail meat category was monitored and analysed. The complexity of this environment is represented in Figure 2. The project tracked multiple abattoir suppliers to multiple processors and multiple processors through to distribution centres (DC) and retail stores nation wide.

In total 100 tracking events were completed. These are represented as follows:

- Stage 1: 10 supply chains from abattoir to retail store were monitored (see Figure 3)
- Stage 2: 90 segments of the different supply chains were monitored to provide a wide sample set reprentive of an Australia wide supply chain. These segments included: abattoir to processor, processor to retail DC and retail DC to store (see Figure 4). Some of the supply chains monitored also included vacuum packed primals sent from abattoir through to retail store butchery that was monitired.

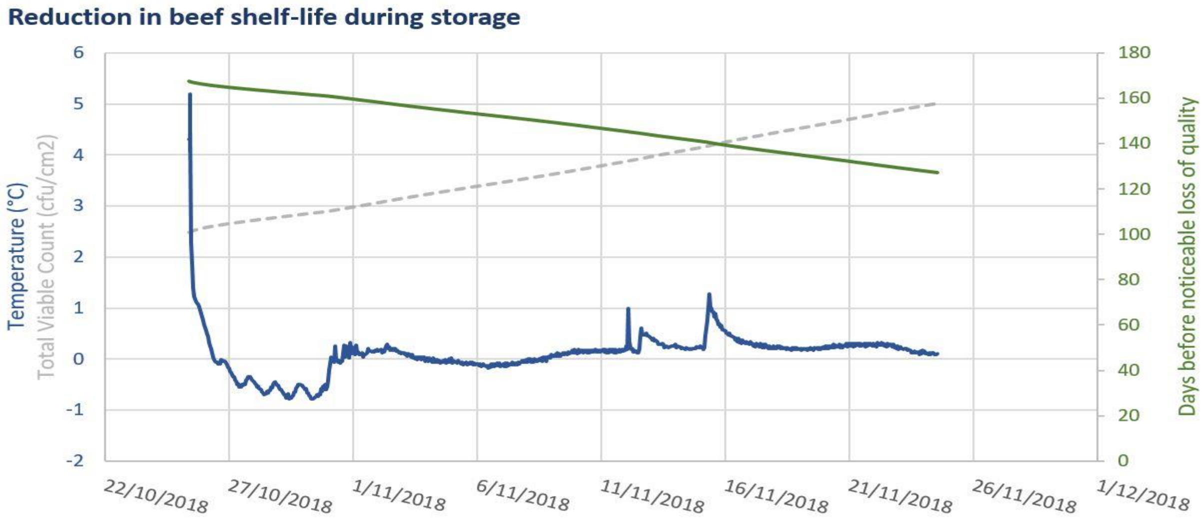

Figure 1: Example of MLA Shelf life algorithm

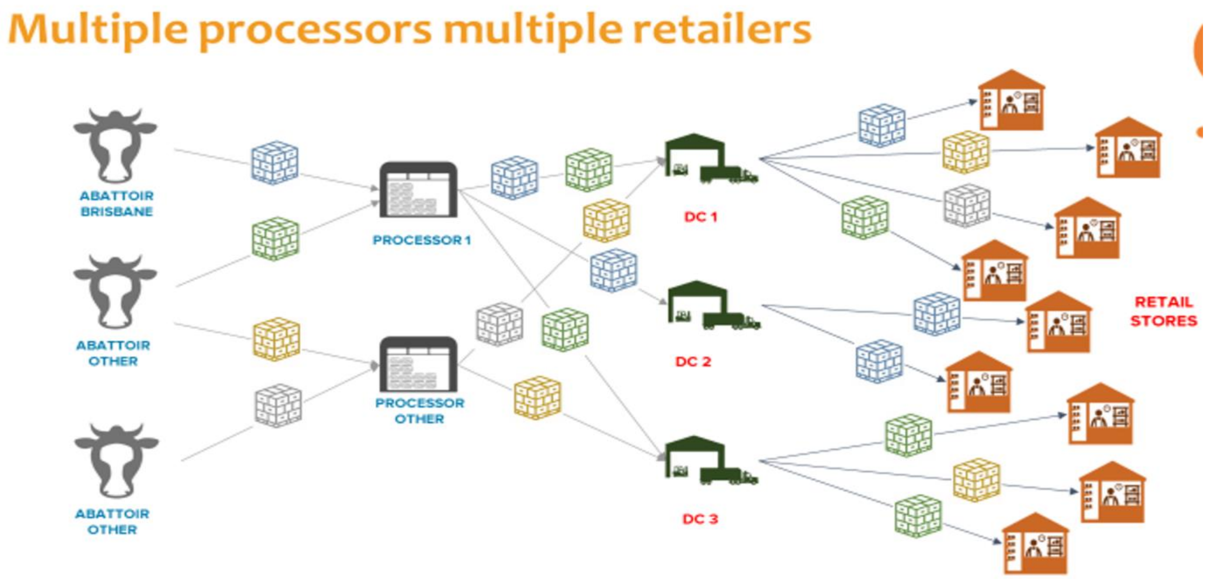

Figure 2: Representive diagram of Australian meat supply chains.

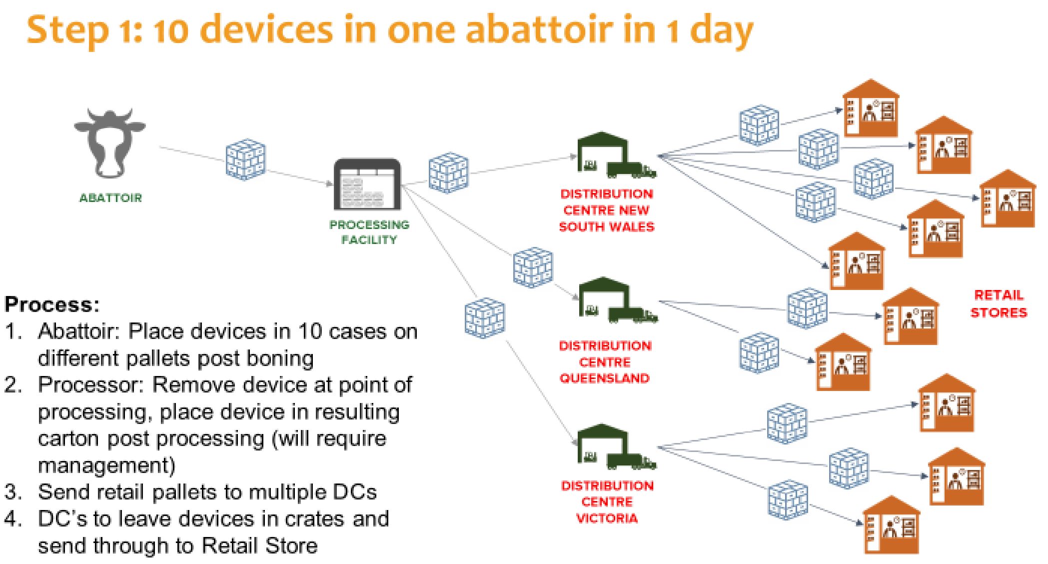

Figure 3: Details of monitoring process employed for monitoring from abattoir to retail shelf

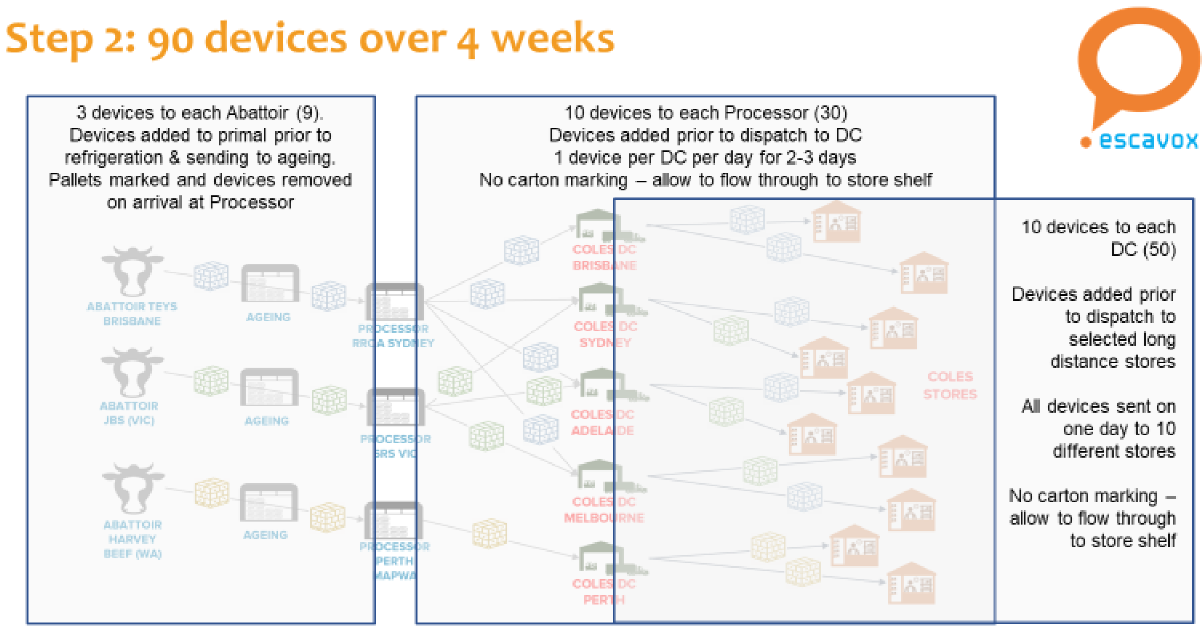

Figure 4: Diagram outlining monitoring process employed for monitoring from abattoir to processor, processor to retail DC and retail DC to store.

4)

To understand the full impact of the long supply chains on product shelf life, the time, temperature and location data that formed the tracks was linked together i.e.tracks from abattoir to processor and processor to store tracks were linked. Additional time to was then allocated to each track to account for the typical handling and movement at store and through to the home environment:

- 5 days was allowed for time in the retail store display cabinets @ 5 degrees celcius

- 2 hours was allowed for transport of product from store to home refrigerator @ 22 degrees celcius
- 6 days was allowed for product to be stored in the consumer's fridge @ 6 degrees celcius

This data was then then inputed into the MLA shelf life model to provide an output of shelf life remaining of VSP portions at retail store.

By segmenting the supply chain into specific legs, it was also possible to show the impact of temperature through the chain and its consequential effect on shelf life.

For each leg of the supply chain MLA recommended temperatures were used. These are shown in Table 1 below.

	Temperature Thresholds		
Supply Chain Legs	Green	Amber	Red
Chilled meat			
Abattoir & Processor (value adder)	-1 to 2 ^{0}C	2.1 to 5 ^{0}C	5.1 ^{0}C or higher
DC	2 to 5 ^{0}C	5.1 to 7 ^{0}C	7.1 ^{0}C or higher
Retail Store	3 to 7 ^{0}C	7.1 to 9 ^{0}C	9.1 ^{0}C or higher
Transport legs	2 to 5 ^{0}C	5.1 to 7 ^{0}C	7.1 ^{0}C or higher
Frozen Meat			
For all leg types	-18 to -30 ^{0}C	-12 to -17 ^{0}C	-11 ^{0}C or higher

Table 1: MLA recommended temperatures for different supply chain legs, showing different temperature thresholds. Green = acceptable, Yellow = marginal, Red = Unacceptable

4 Results

4.1 Stage 1 results

Stage 1 results represent the data and analysis of from the monitoring of 10 supply chains from abattoir ro retail shelf. Each individual journey from one location to another is described as a a 'track'.

In Stage 1, meat was tracked from abattoir through to processor, the primals were then tracked through the processing facility and the same device was then installed into retail ready pack through to DC or store.

The information dashboard below below (Figure 5 and 6) provides an indication of the time the the product was within the recommended temperature ranges for the different legs.. The average temperature for the 10 tracks across all legs was 2.1 degrees with an average of 25.5 days from abattoir through to retail store cold room. Escavox VOP score or Voice of Produce score represents the time of the journey spent in the nominate temperature. Average VOP for the above 10 tracks was 73%, so 27% of total time the meat spent in the in the supply chain it was outside of the nominated temperature ranges.

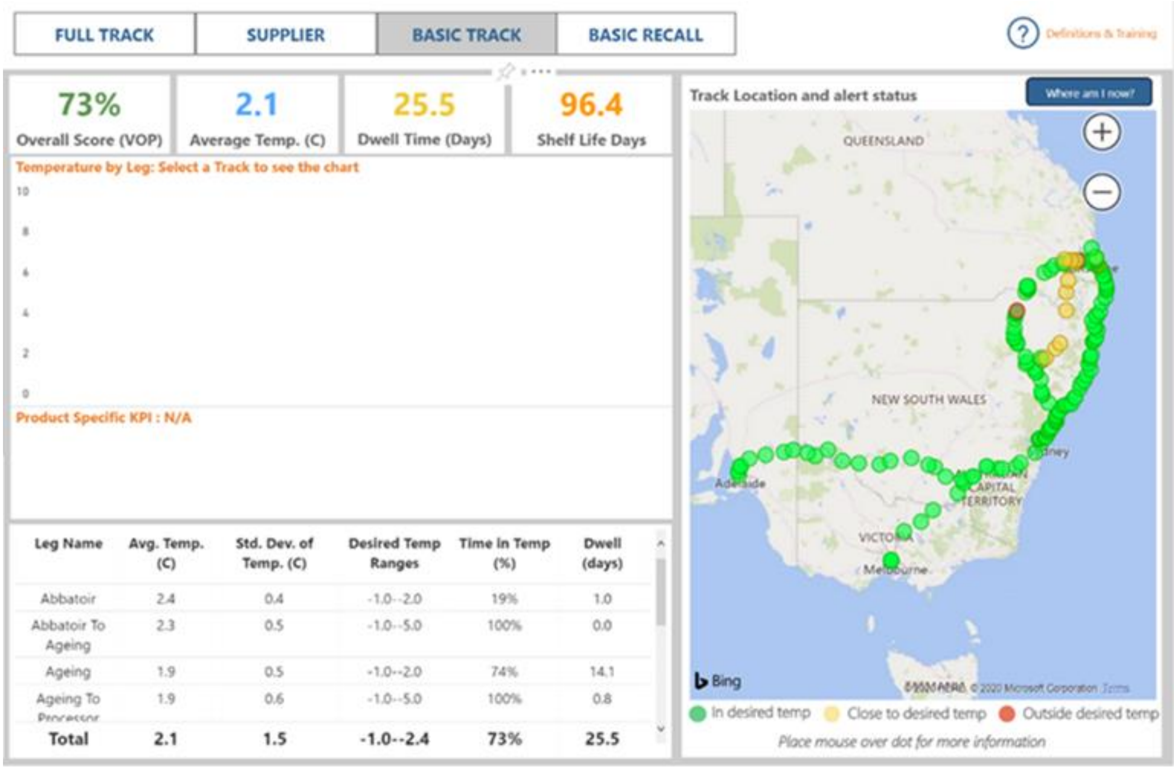

Figure 5: Information dashboard 1 showing aggregated data of 10 supply chains from abattoir to retail store

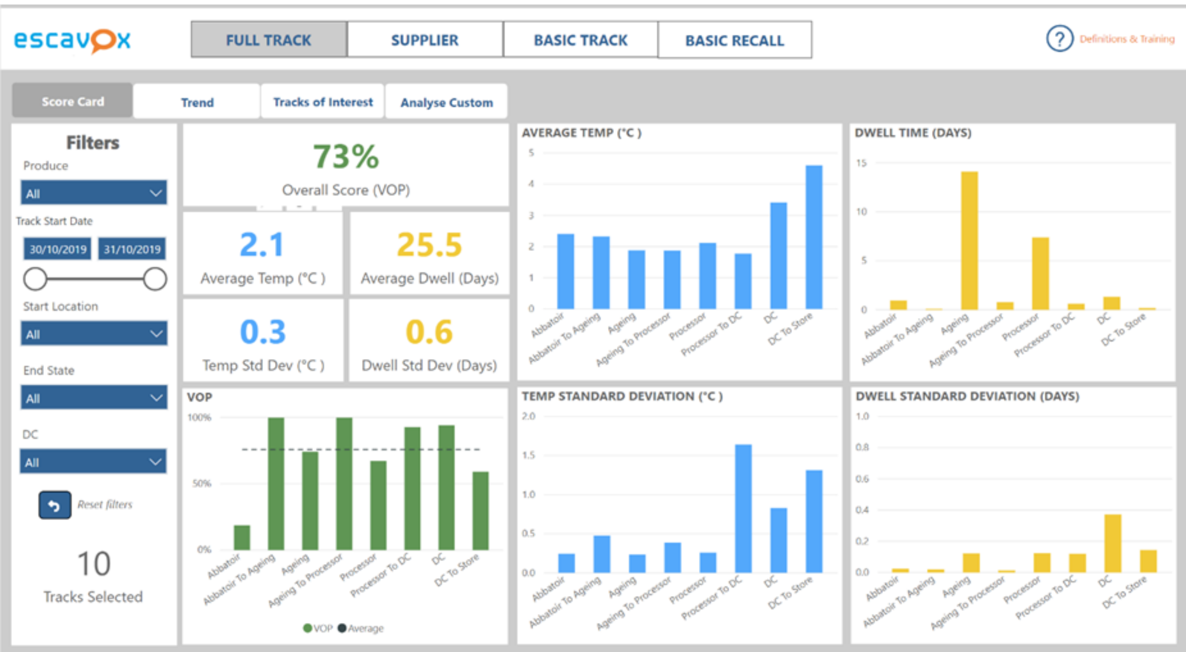

Figure 6: Information dashboard 2 showing aggregated data of 10 supply chains from abattoir to retail store

Examples of tracks that followed primals converted into retail ready packs are shown in figures 7, 8 and 9. Which shows excellent temperature control throughout all legs of the supply chain in these examples

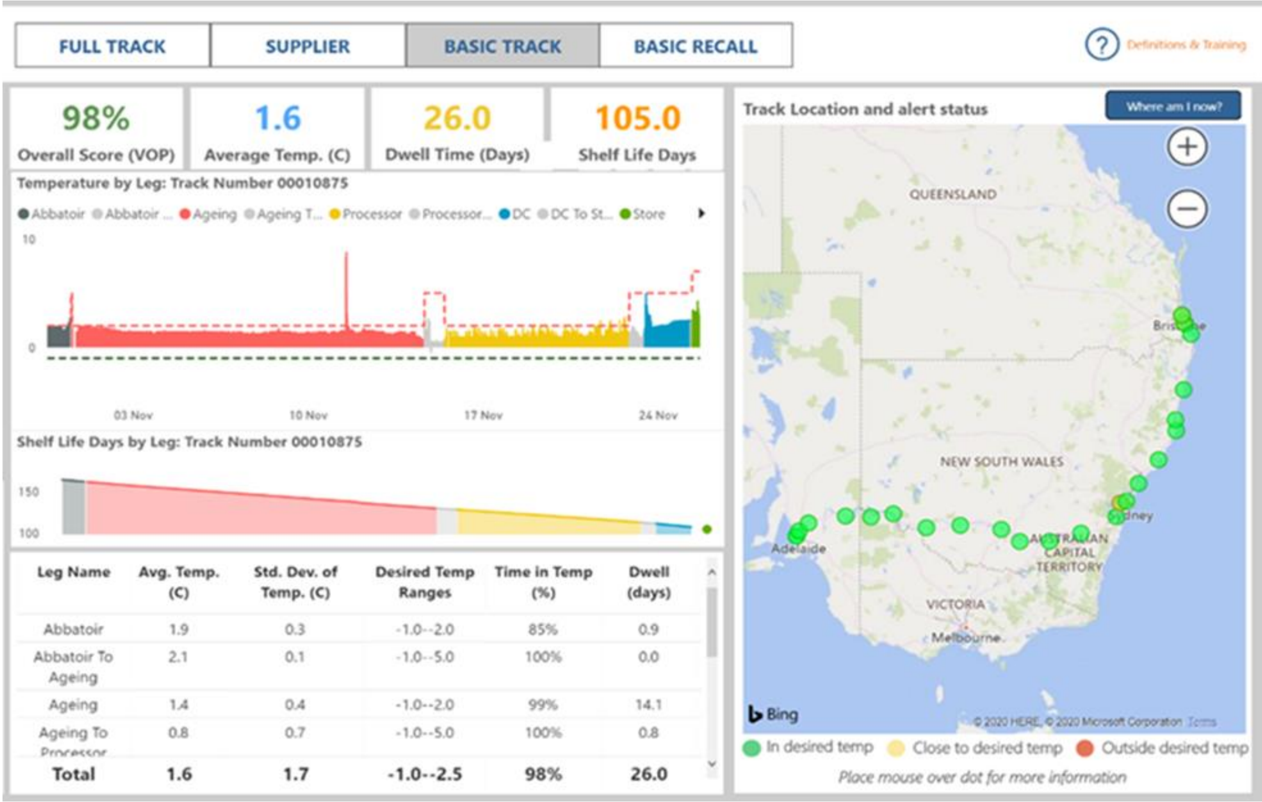

Figure 7: Track from abattoir through to retail store, device moved from primal to retail ready pack at processer/value adder plant with remaining shelf life days

4.2 Stage 2 results

Stage 2 results represents 90 tracks applied to segments of the different supply chains to provide a sample set representive of Australian meat supply chains. These segments included abattoir to processor, processor to retail DC and processor to retail store, as well as vacuum packed primals sent from abattoir through to retail store butcheries.

As would be expected, journeys from retailer DC to stores in regional Australia were the typically longer. The result also show that maintaining optimal temperatures on regional routes, and particularly in January, is challenging. This is indicated by the out-of temperature data points (yellow and red) on the heat map in Figure 10 shown below.

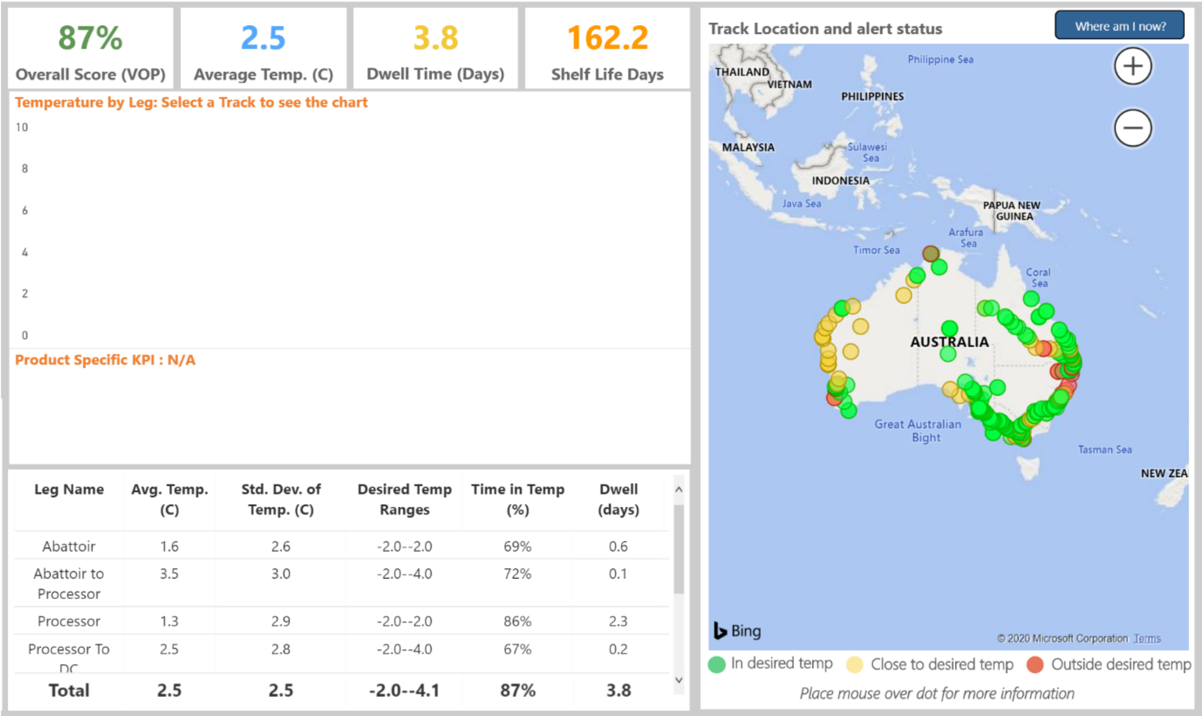

Figure 10: Information dashboard 3 showing aggregated data of 10 supply chains from abattoir to retail store

The Escavox platform aggregates the tracks into the various legs to show the standard temp and dwell time for each of the legs tracked. As well as the average of deviations in each of these legs to provide a whole of trial snapshot and scorecard of the track data.

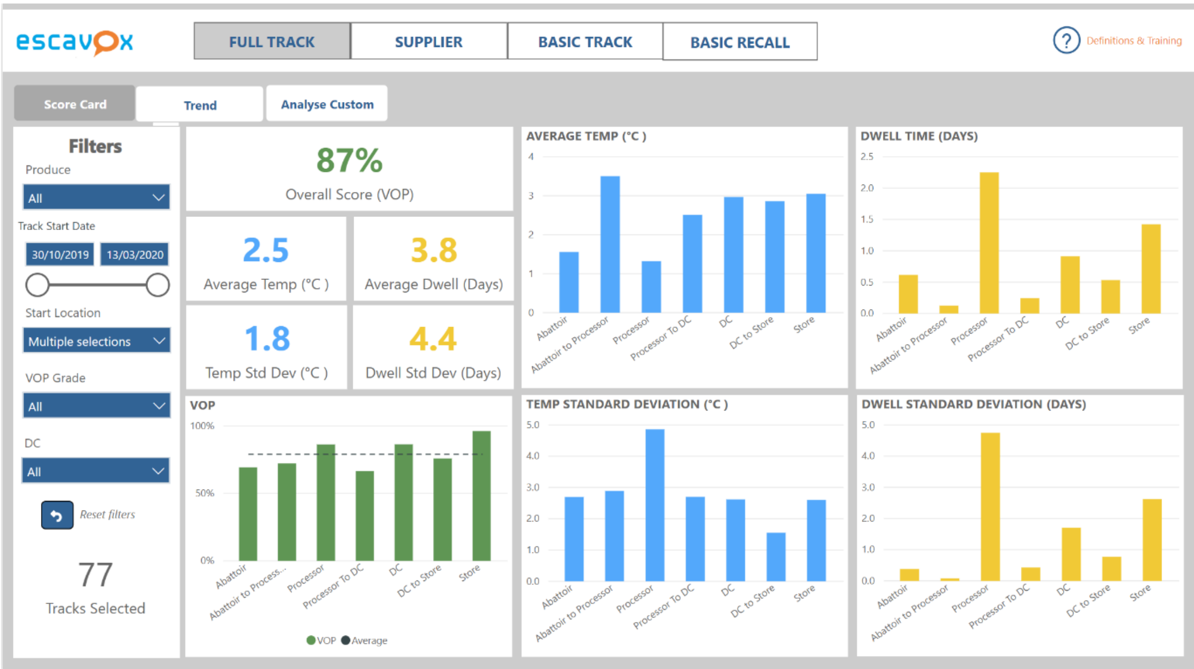

Figure 11 : Information dashboard 4 showing aggregated data of 77 tracks across Australia wide sample of supply chains from abattoir to retail store

The following tracks are examples of section of the Australian domestic retail supply chain:

4.3 Linked tracks results

The linked tracks, which capture data from abattoir to store and then allocate nominal time and conditions time for shelf and home conditions, were modelled using the MLA shelf life algorithm to calculate remaining shelf life of VSP portions. The results were starkly different to the current 'best before' dates added at the processing plant. Australian supermarket benchmark for VSP retail ready portions have a 'best before' date added at processing facility of 16 days.

For example, in the pilot, the longest track though to the consumer fridge was 23.9 days (see details in Figure 18 below). This showed that is product is held at -0.5 ^{0}C, after the allocated 6 days in the refrigerator then the remaining shelf life would be 67.4 days. As storage at -0.5 ^{0}C in the home refrigerator is not representative, modelling was done on alternate storage temperatures in the home refrigerator to show all possible outcomes of shelf life remaining at the end of longest track (23.9 days). Table 2 belows shows the findings:

Temperature	Estimated remaining shelf life (days) after 23.9 days in supply chain
-1 ^{0}C	88
0 ^{0}C	53
1 ^{0}C	35
2 ^{0}C	25
4 ^{0}C	15
6 ^{0}C	10

Table 2: Influence of temperature on remaining shelf life of product at the end of the longest track (23.9 days)

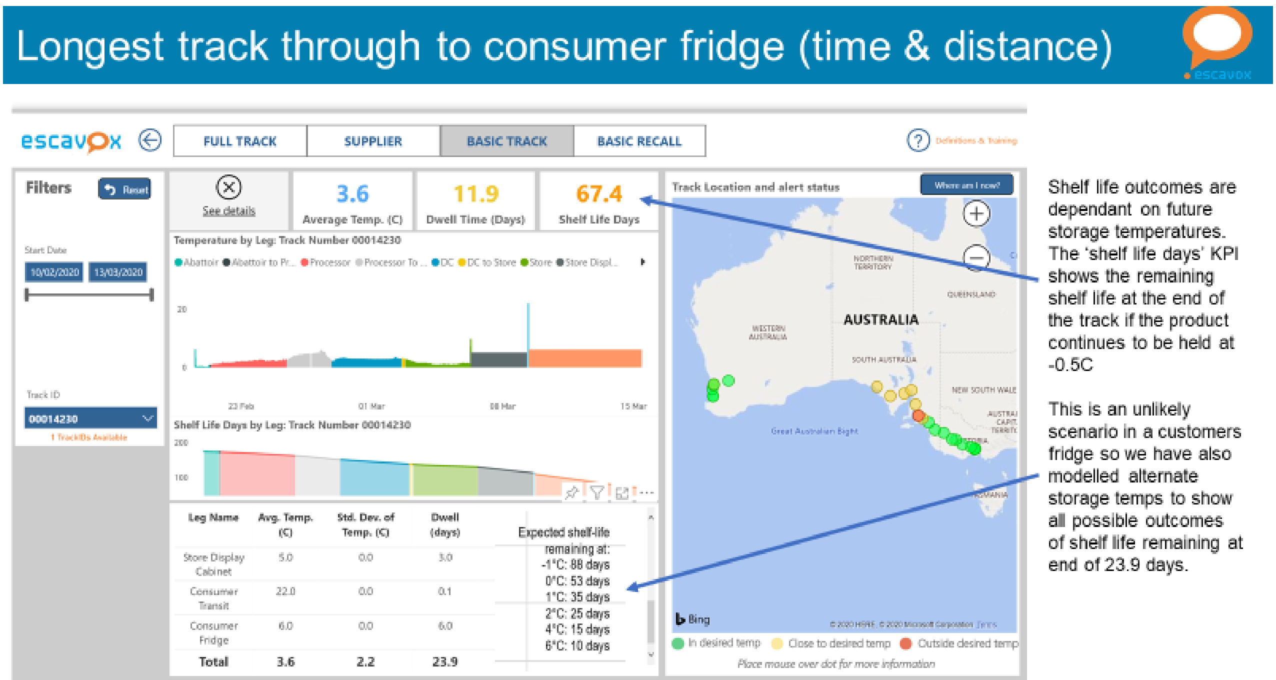

Figure 18: Details of the longest track through to a consumer refrigerator

The best track through to consumer refrigerator was 19.8 days and modelling indicated that the product had 108.1 days remaining shelf life if was held at -0.5 ^{0}C, after the allocated 6 days in the refrigerator (see Figure 19). Again as storage at -0.5 ^{0}C in the home refrigerator is not representative, modelling was done on alternate storage temperatures in the home refrigerator to show all possible outcomes of shelf life remaining at the end of this track. Table 3 belows shows the findings:

Temperature	Estimated remaining shelf life (days) after 19.8 days in supply chain
-1 ^{0}C	136
0 ^{0}C	82
1 ^{0}C	55
2 ^{0}C	39
4 ^{0}C	23
6 ^{0}C	15

Table 3: Influence of temperature on remaining shelf life of product at the end of the longest track (19.8 days)

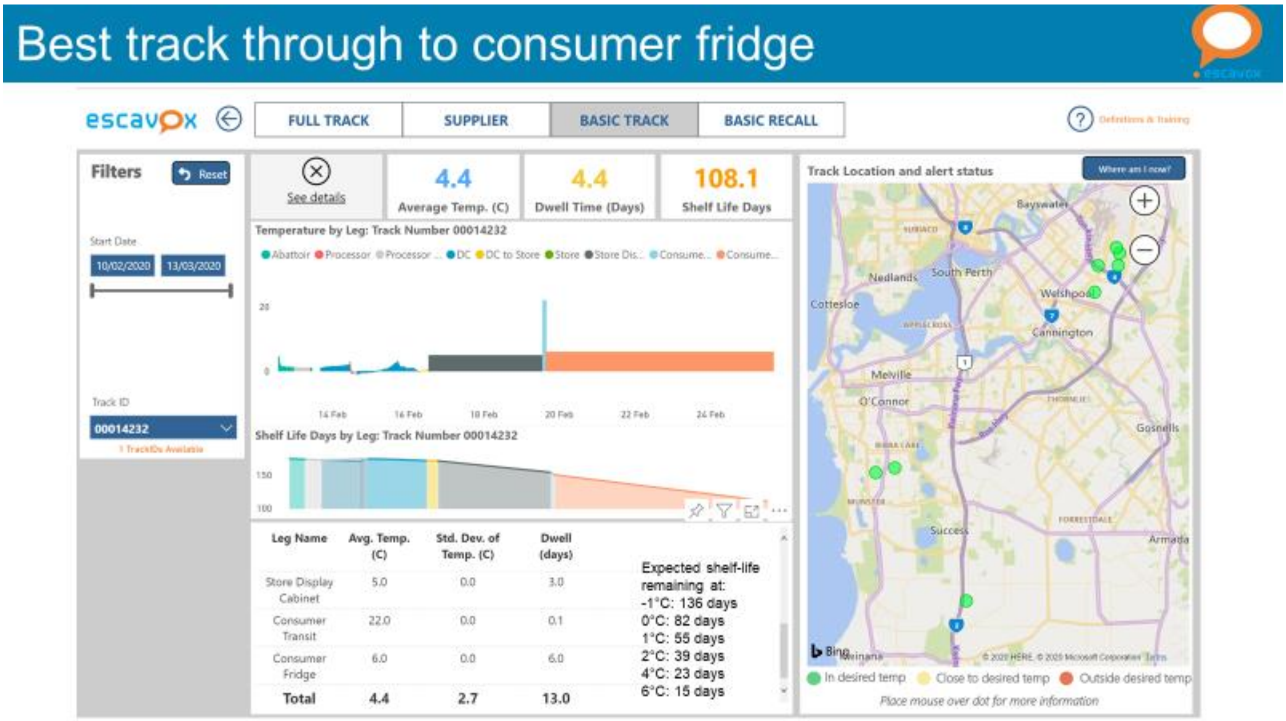

Figure 19: Details of the best track through to a consumer refrigerator

5 Discussion/Findings

5.1 Tracking primals through to portion retail ready

The current meat supply chain is complex with multiple abattoirs supplying VP primals to multiple processing facilities. Product is also delivered in varying ages from aging facilities and processors may be handling primals for multiple vendors primals at the one time. As with many fresh food supply chains, it is difficult to know at the commencement of the process i.e. at the kill stage, who the customer may be and the supply chain through which the product may travel. Hence, with the limitation of current technology it is difficult to track from end-to-end with the one tracker. As a result it was necessary to link tracks (data) together to create this scenario for the the purposes of this pilot. .

For stage 1, on 10 occasions (as shown in Figures 6, 7, 8), a primal was marked at the processor and a tracker was installed into the portion cut of the marked primal. This approach allowed the opportunity to apply the shelf life model to this portion retail ready cut from abattoir through all the legs through to retail store. However the process was time consuming and took a number of staff to coordinate, and hence cannot be replicated at scale. For these reasons, in Stage 2, we tracked various legs of the supply chain and linked these together (see section 4.3 Linked Tracks).

5.2 Tracking various legs (segments) of supply chain

Supply chains are complex non-linear systems, and interpreting data accurately requires contextual awareness of where a product is (location or geo-centre), its condition and the temperature and time at there is constant interaction occurs at points that can be locations or geo-centres, temperature, and characterising a scenario accurately requires contextual awareness.

The challenges that the non-linear characteristics of a supply chain present requires a new algorithmic method that automatically provides contextual awareness (e.g. correct allocation of leg type), computed in real-time. Inversely, key data may be missing from IoT device data captured, and the algorithmic method needs to be able to accommodate this.

Hence any logic that is applied to a track needs to be capable of:

- automated end to end supply chain data capture and analysis, dealing with decoding large data sets from IoT devices to accurately establish key events in complex supply chain scenarios,overlaying predictive analytics with contextual awareness, and machine learning, to establish a decision support system for optimal treatment of food products,
- providing a holistic view of a supply chain.

This presents a unique problem for which there is no known models that can be referenced. All prior models have taken a deterministic approach which:

- requested information at key points and are not fully automated, and
- only applied historical data; could not process in real-time with contextual awareness to level of accuracy sought

Due to the complexities of the selected retail supply chain with multiple legs and multipe originating sources. The the second part of the project (Stage 2) aimed to track individual legs. They were:

- Abattoir to processor
- Processor to DC
- DC to store
- Processor to Store

This then allowed a wider view of the Australian meat supply chain to be investigated and the opportunity to apply the MLA shelf life model to each leg of data to ascertain the impact of time and temperature on each leg.

The results showed:

- There is considerable difference in the performance of Australian meat supply chains and the resulting shelf life. For example the longest track recorded the shelf life of meat was 67.4 days @ 0.5 degrees (figure 9) compared with the best track which showed 108.1 days @ 0.5 degrees (figure 10).
- VSP product has additional shelf life compared to alternative packing methods. The remaining shelf life days reported are comparable to previous MLA report P.PIP.0563 and P.PIP.0453. https://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Product-Integrity/Shelf-life-of-Australian-meat/3520
- If a processor delivers at optimum temperatureto DCs, DC's are well placed to maintain temperature. If product is delivered above optimum temperature specifications, the product needs to be re-chilled which potentially adds refrigeration costs and dwell time, as well as the inherent loss of shelf life.
- For current VSP product, several days shelf life can be added allowing product longer on shelf and reducing markdowns as show by the research of the linked tracks (see Figures 18,19)

The shelf life of red meat may vary greatly depending on the conditions to which the product is exposed in the different supply chains.

We have found that some of the long haul routes from capital city supermarkets distribution centres to regional stores to be the most challenging in terms of optimising the shelf life capacity of meat for retail store / consumer.

5.3 Potential application of findings

This project only tracked 100 legs of the meat supply chain, which is a very small subset of journeys travelled by Australian meat domestically. It has however provided insights and identified areas where benefits may arise and where further research could be undertaken to realise the benefits. There are potentially opportunities for industry to gain greater benefits by building on the existing shelf life modelling and developing more refined and models, with practical industry application. To achieve this further research / validation may address:

- Tracking of retailers supply chain to provide a base line data which could be applied to shelf life model to identify the supply chains (and stores) that would have a higher risk of attracting product compliants and product quality.
- Applying the shelf life model based on historical and real time data to provide model-based 'used by' dates, as opposed to the existing 'used by' date systems
- Use modelling to provide prediction of shelf life on specific supply chain routes based on historical data.
- Continuous tracking to offer direct ROI via extended shelf life (reduced loss/markdown) and operational efficiency (fewer rejections/operational delay)
- Use of the shelf life model 'use by date' method to reduce the need processors to undertake laboratory testing of every product line.

- Utilising the holding capacity of processors to hold product at low temperatures, to better manage flow of product in the supply chain. This could specifically apply to help manage retail promotions, other supply / demand fluctuations and working capital, whilst optimising shelf life attributes of the product.

6 Conclusions/recommendations

6.1 Conclusion

The project has allowed the current supply chain of red meat through a variety of domestic retail supply chains to be investigated. As a result this has provided the opportunity to draw a number of conclusions:

- There is considerable variability of the cold supply chain from abbatoir to processor and processor to retail store, which affects the potential shelf life of meat at retail shelf and in the home.
- The potential of VSP red meat has additional shelf life days not considered under the current 'best before dates' system.
- Results show that there are challenges in maintaining the cold chain in regional long haul transport legs which impacts the shelf life potential of the product.
- There are a number of areas where further research / validation would assist the industry to maximise the opportunities from shelf life model work already completed.

The sample size of the pilot undertaken in this project is (100 tracks) is too small to make temperature control and reject parameter change decisions. A larger scale pilot to further validate findings across majority of higher risk and longer supply chains store shelf and to address some of the potential applications of the findings to date is desirable.

6.2 Recommendations

The following recommendations are proposed:

- Due to the small number of tracks undertaken in this project relative to the size and complexity of Australian meat industry, it recommended that a further in-depth pilot of up to 1,000 tracks across Austalian domestic supply chains is undertaken. This would provide the evidence to build a case for industry or retailers to consider adoption of the MLA shelf life model for basis of creating new 'best before date' recommendations for VSP product. It would also allow other shortcomings and applications of finding s identified in this report to be tested.
- From a shelf life perspective brand owners should consider moving beef to VSP packaging where
- To de-risk potential food safety issues and maintain value in the brand, brand owners should continuously audit problematic supply chains, to identify breaches of temperature specifications, until unlying issues can be addressed.