Final report

Temperature, shock and location tracking of chilled beef through international and domestic supply chains by air and sea

Project code: P.PIP.0580

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Date published: 30 May 2022

PUBLISHED BY
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This is an MLA Donor Company funded project.

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

Abstract

The MLA/University of Tasmania shelf-life model has been available to industry for several years. Linking this model with real-time temperature monitoring will provide industry and their customers with the tools to improve distribution logistics and aid in understanding the impact of transport conditions on product shelf-life. International and domestic shipments (n=162) were monitored in real time for temperature and other parameters to identify points along the transport chain that impact of product shelf-life and wholesomeness. The shelf-life remaining for product on reaching its destination decreased with increased shipping time and increased holding temperature. This information formed the basis of discussions with customers around product shelf-life and wholesomeness and resulted in reduced claims and changes to storage practices during distribution. A shelf-life study undertaken at Processor A supported the model predictions. This work highlights the benefits of real-time monitoring of product temperature and feedback of predicted shelf-life remaining for product on arrival at destination.

Executive summary

Background

The University of Tasmania and MLA have developed a model for predicting the shelf-life of vacuum packaged red meat based on time/temperature data matched to the different links in the food chain. To demonstrate the usefulness of predictive modelling linked to real-time temperature monitoring, trials were undertaken using TIVE data loggers incorporated within international and domestic fresh meat shipments. Data generated was used to estimate the shelf-life remaining at various points during distribution and to provide a basis for discussions with customers.

Objectives

This project's main objective was:

- Collect and analyse time/temperature data to help improve distribution logistics and understanding impact of transport on product shelf-life

Secondary objectives were:

- Identify links within the cold chain that impact on shelf-life.
- Identify areas where changes can be made to supply chain management to improve product shelf-life.
- Quantify the benefits arising from the application of the approach.

Methodology

TIVE Solo5G single use loggers were used for recording product temperature as well as humidity, light, motion, and shock. Loggers were placed in cartons at the time of packing. For some shipments (to improve logger functionality and map temperatures throughout a container) a 'Sentinel' logger was placed in the container next to the door with 'Beacon' loggers placed in cartons throughout the container. Temperature was monitored until product reached its destination. Temperature data was analysed to determine shelf-life remaining using the University of Tasmania/MLA shelf-life prediction tool. Shock measurements were used to identify point in the supply chain where handling issues may have impacted on product integrity. Shock values greater than 5G indicate a serious impact event and warrant immediate investigation

A shelf-life study was undertaken for skin-packed boneless cube roll and flex-pack beef mince. Samples were stored at Processor A under controlled temperature conditions. At set time points samples were assessed for wholesomeness (odour, colour and appearance), aerobic plate count and Enterobacteriaceae.

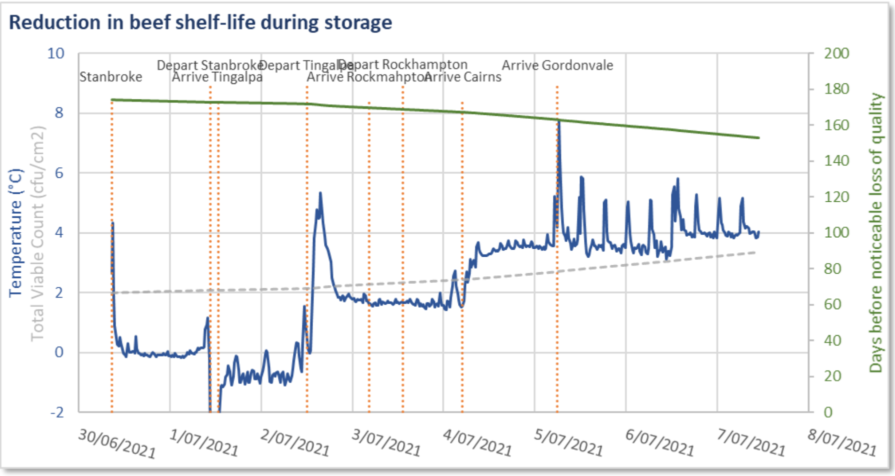
Results and Discussion

Time/temperature data was linked with location data to provide a map of the temperature history of product throughout transport. This data was inserted into the predictive model to provide a shelf-life history for product. The shelf-life model predicts a shelf-life of 174 days when product is stored at an optimum temperature of -0.5 °C.

Tracks from 162 shipments to both international and domestic customers were analysed using the shelf-life model. Not surprisingly, the shelf-life remaining for product on reaching its destination

decreased with increased shipping time. With product arriving by sea having lower remaining shelf-life than product transported by air or road (domestic only). In general, sea freight was at a lower temperature than air or road freight.

Temperature data was used to inform customers of issues with storage throughout distribution. The model allows temperature and shelf-life to be tracked throughout distribution (see figure below).



Temperature (blue line), Shelf-life solid green. Broken red lines represent key points in the transport chain as identified by GPS data. The broken grey line is the $\log_{10}$ increase in aerobic plate count.

This information has been useful to both Processor A and customers in discussions around product shelf-life and distribution systems. The relatively high temperature during storage at destination in the figure above, was shown to significantly impact on product shelf-life. Shock readings were also useful in identifying points in the supply chain where handling may have resulted in a loss of packaging integrity.

Key findings

- Feedback of temperature history data to customers resulted in reduced claims relating to product wholesomeness.
- Temperature monitoring throughout transport allowed customers to identify problematic areas within their distribution system. Information was passed onto managers to reinforce the need for tighter temperature control and to implement corrective actions.
- Real-time logging has removed the issue of having to return loggers for analysis.
- While there is a financial benefit to mapping cold chains the main benefit is in understanding the various customer cold chains and providing customers with confidence in the shelf-life of Processor A product.
- The attributed benefits are only realised when an issue occur, for example pushing back on local delivery company due to poor handling can save $25,000 per case.
- Export customers claims can varied between $125 – $200,000. The occurrence of temperature abuse situation are random, on average industry reported savings on claims can be up to $600,000 per annum.
- Incorporation of the shelf-life model into the TIVE platform allow Processor A to rapidly inform customers of the impact of cold chain management decisions on product shelf-life.

Benefits to industry

Real-time temperature monitoring in conjunction with shelf-life prediction will allow industry to discuss cold chain issues with customers avoiding costly claims and providing customers with confidence in the shelf-life of product.

Future research and recommendations

- Tive to setup a portal where customers can download logger data in real.
- Verification of the ability of the shelf-life model to accurately predict remaining shelf-life for mince and retail-ready packs.

Conclusions

The implementation of real-time temperature logging of products shipped to both domestic and international customers was found to be a valuable tool in informing customers and Processor A of potential issues in relation to cold chain management. Incorporation of shelf-life modelling allowed customers to be notified of issues that may impact on product wholesomeness.

Table of contents

1. Background

The University of Tasmania and MLA have developed a model for predicting the shelf-life of vacuum packaged red meat, which has been available to industry for several years (V.MFS.0402). However, in the past its utility has relied on the availability of accurate time/temperature data that can be matched to the different links in the food chain. Until recently obtaining such data has been problematic for a number of reasons, mainly due to logger functionality and the requirement for retrieval from customers. Previous work published by MLA (P.PSH.1247 – Proof of concept for international cold chain monitoring and automated reporting) has demonstrated the benefits of real-time temperature monitoring and reporting, including:

- Reduced transport costs by demonstrating control of shelf-life during sea freight.
- Ensuring price is protected for longer with clear data on the shelf-life remaining for product on arrival to the customer.
- Reducing rejections (and hence reduced insurance premiums)
- Opening export markets by providing customers with real-time shelf-life data

Currently several real-time monitoring systems are available to Australian industry. Initial trials of the TIVE system, carried out at Processor A Pty Ltd, have shown that real-time temperature logging can lead to a dramatic shift in responsibility for product wholesomeness and changes in how Processor A negotiates with customers. To demonstrate the usefulness of real-time temperature monitoring and reporting, further trials were undertaken using TIVE data loggers incorporated with international and domestic product. Data generated was used to estimate the shelf-life remaining at various key points during distribution using the University of Tasmania/MLA shelf-life model.

2. Objectives

This project’s main objective was:

- Collect and analyse time/temperature data to help improve distribution logistics and understanding of impact on product shelf-life and to develop processes and procedures within Processor A to monitor improvements on a continual basis.

Other objectives were:

- Identify links within the cold chain that impact on shelf-life through temperature variances, shock factors and location tracking.
- Identify factors impacting on chilled beef shelf-life for different customers.
- Identify areas where changes can be made to supply chain management to improve product shelf-life.
- Quantify the benefits arising from the application of the approach taken to improving cold chain management by documenting reductions in claims against the business and improved quality of and demand for product.

3. Methodology

3.1 Temperature Logging

3.1.1 TIVE temperature loggers

TIVE Solo5G single use loggers were used for recording product temperature as well as humidity, light, motion, and shock. Temperature accuracy was ±0.5 °C, with calibration traceable to ISO 17025. Loggers have a typical battery life of 90 days, but this can be extended by increasing transmission time. Location is recorded through a combination of cellular, GPS and Wi-Fi geolocation. Loggers weigh 100g and measure 96 x 58 x 19.5mm. Tive Beacon loggers were used when multiple loggers were placed throughout a container. Beacon loggers transmit data back to a Solo5G logger, placed near the door of the container, which captures and transmits the data. This aided in real time capture from loggers placed deep within a container.

Figure 1. Tive Solo 5G logger

The following observation relating to loggers were made:

- In some cases, due to the pandemic, journeys were delayed. This resulted in loggers running out of battery prior to completion of the journey. This has been partially resolved by increasing the time between transmissions, thus conserving battery life. Initially loggers were set to record every 30 minutes and transmit every 2 hours. The transmission time was increased to 4 hours in an effort to conserve battery life.
- Some loggers 'failed' during shipment with most 'failures' due to loss of battery life. Some 'Beacon' loggers also failed to accurately show remaining battery life making deployment problematic.
- It was noted that in some air freight tracks, location data jumped from the departure port to another country and then back to the destination port on arrival. This was thought to be issue with Wi-Fi connectivity, TIVE is investigating.
- Currently most loggers are not returned and are destroyed by the customer. This adds to the cost of the loggers and the ability to recycle loggers would reduce costs and have less of an environmental impact.

3.1.2 Temperature monitoring

Loggers were placed in cartons at the time of packing and an identifying number placed on cartons. For some shipments (to improve logger functionality and map temperatures throughout a container) a 'Sentinel' logger was placed in the container next to the door with 'Beacon' loggers placed in cartons throughout the container. Commencement of logging varied between loads with some loggers attaching to shipments weeks before product had left Processor A. This resulted in an unnecessary drain on battery life. Solutions are currently under investigation. Temperature was monitored until product reached its destination as defined by the customer address. This proved problematic as in some cases the address of the customer was not the physical address where the cartons were finally processed.

Real-time temperature data for shipments is available on the TIVE web site and final data can be downloaded as a comma separated variable (CSV) file for analysis. An analysis report (without shelf-life prediction) is available for all shipments as a printable PDF file. There are some issues with file formatting, in particular date formatting, that make analysis of the data more time consuming. This needs to be further investigated.

Temperature data was analysed to determine shelf-life remaining using the University of Tasmania/MLA shelf-life prediction tool. For the purposes of this analysis model parameters were set to product type beef with a starting count of 100 CFU/cm^2.

3.1.3 Shock measurement

Shock was measured by the loggers as acceleration in gravities. A shock value below 3G is considered typical for movement of cartons and pallets. Shock values between 3 and 5G are worthy of note and may indicated inadequate handling of cartons. Values in this range may be useful when discussing damage claims with customers. Shock values greater than 5G indicate a serious impact event and warrant immediate investigation as they can lead to loss of product integrity.

3.2 Shelf-life study

To verify the predictive model a shelf-life study was undertaken at Processor A with product stored under controlled temperature conditions and monitored for bacterial numbers and wholesomeness by an independent testing laboratory. Product, skin-packed boneless cube roll and flex-pack beef mince, was processed at Processor A following normal practices. Selected packs were placed in cartons and stored in a shelf-life cage in the load-out facility. At predetermined times cartons were opened and representative packs removed and transported to Symbio Laboratories (Brisbane) for analysis. Product was assessed at Symbio for wholesomeness (odour, colour and appearance) and samples collected for enumeration of aerobic plate count (AOAC 990.12, Curiale et. al., 1990) and Enterobacteriaceae (ISO 21528-2).

3.3 Data analysis

Temperature tracks were downloaded from the TIVE web site using the 'Shipments/Completed" menu option to identify completed shipments. A current issue with the TIVE platform is date formatting. Currently the easiest method for converting dates from US to Australian format is to change the regional settings during opening and saving of downloaded files. Once data files were in Excel™

format, location data (GPS) was used to identify key stages during transport and storage. An example of the data generated for each individual shipment is provided in Figure 2 and Table 1**.**

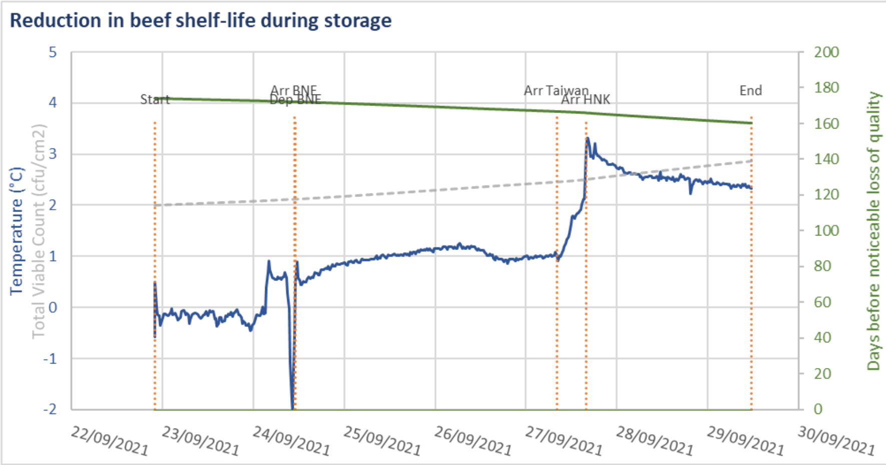


Figure 2: Temperature (blue line) of product exported from Processor A (Start) by air (Brisbane Airport, BNE) to Hong Kong (HNK) via Taiwan. Solid green line is the shelf-life remaining in days (right hand axis). Broken vertical red lines represent key points in the transport chain as identified by GPS data collected by the logger. The broken grey line is the $\log_{10}$ increase in aerobic plate count during transport.

Table 1: Shelf-life data calculated from the temperature history of product air freighted from Processor A to Hong Kong

Event	Date/Time	Duration (Days)	Avg. Temp [a] (°C)	Shelf-life Consumed (Days)	Shelf-life Remaining (Days)	Shelf-life consumed (%)
Start	22/09/2021 22:01	0.00	0.00	0.00	174.25	0.0%
Arr BNE	24/09/2021 10:47	1.53	-0.09	1.87	172.38	1.1%
Dep BNE	24/09/2021 11:07	0.01	0.49	0.02	172.36	0.0%
Arr Taiwan	27/09/2021 8:10	2.88	0.97	5.42	166.94	3.1%
Arr HNK	27/09/2021 15:49	0.32	1.62	0.76	166.18	0.4%
End	29/09/2021 11:30	1.82	2.58	5.76	160.43	3.3%

[a] Average product temperature during the transport leg described by 'Event'

The University of Tasmania/MLA shelf-life prediction tool was used to estimate the shelf-life of product at various points during transport and storage. The model predicts a shelf-life of 174 days when product is stored at an optimum temperature of -0.5 °C. It should be noted that the shelf-life model was developed from data collected from vacuum-packaged whole muscle beef and sheep product and has not been validated for small cuts and mince or for other packaging technologies.

The shelf-life remaining reported in Table 1, is the predicted shelf-life of product on arrival at destination if subsequently stored at -0.5 °C. The data in Table 1 can be used to identify steps in the distribution chain that have the greatest impact on product shelf-life. The model can also be used to estimate the remaining shelf-life of product when stored at temperatures other than -0.5 °C.

4. Results and Discussion

4.1 Shelf-life Remaining

Tracks from 162 shipments to both international and domestic customers were analysed using the University of Tasmania/MLA shelf-life prediction tool. Only one set of logger data was analysed per shipment i.e., where multiple loggers were placed in the shipment only the logger in contact with product recording the highest temperature was used. A summary of the findings is provided in Appendix 1. Not surprisingly product travelling by sea took longer to reach its destination than product transported by air or road Figure 3. Road freight was to domestic markets only.

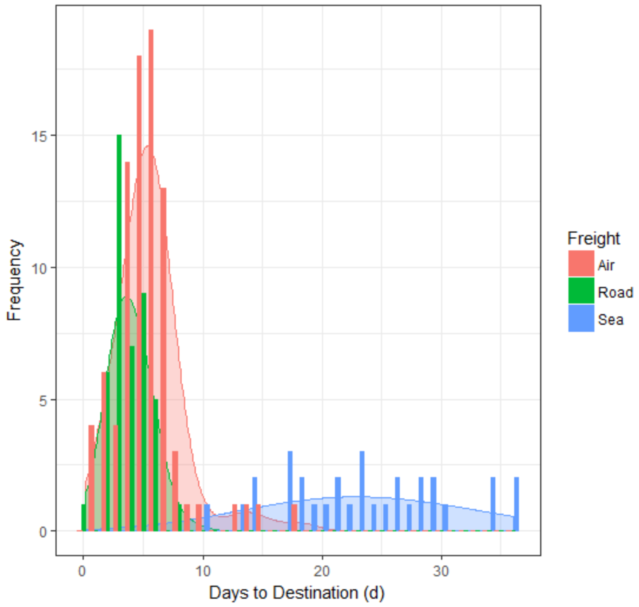


Figure 3: Distribution of travel times for vacuum packaged beef transported by air, road and sea

The shelf-life remaining for product on reaching its destination was correlated to the shipping time (Figure 4). Two outliers were removed from the data presented in Figure 4, both were for product shipped to Japan, both tracks showed loss of temperature control mid-way through transport. This could have been due to a logger malfunction or to the loggers being physically removed from the container.

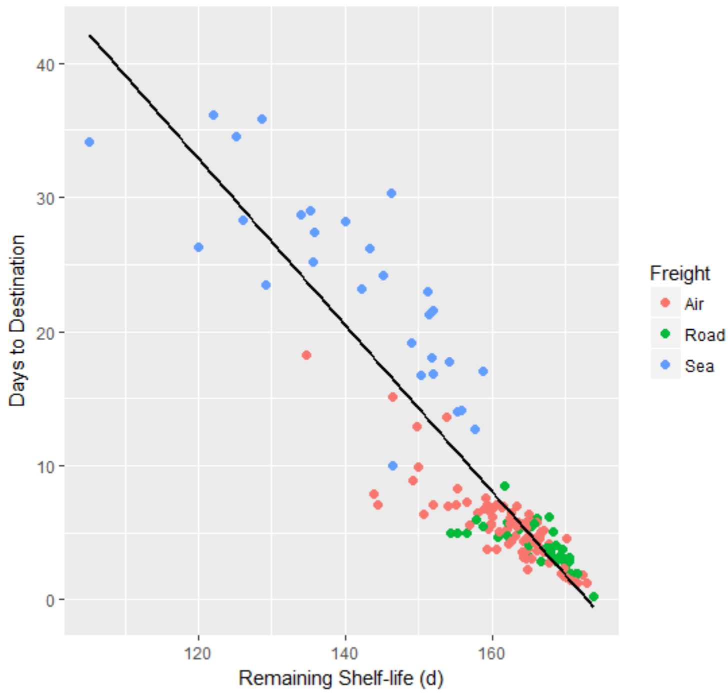


Figure 4: Effect of transport time on the shelf-life remaining on arrival at the destination

Surprisingly temperature control during transport was inversely related to the duration of transport i.e., product shipped by air had higher average temperatures than product shipped by sea (Figure 5), this was also reported in project P.PSH.1247[1]. The one high product temperature for sea freight was one of the Japanese shipments that lost temperature control mid-way through the journey.

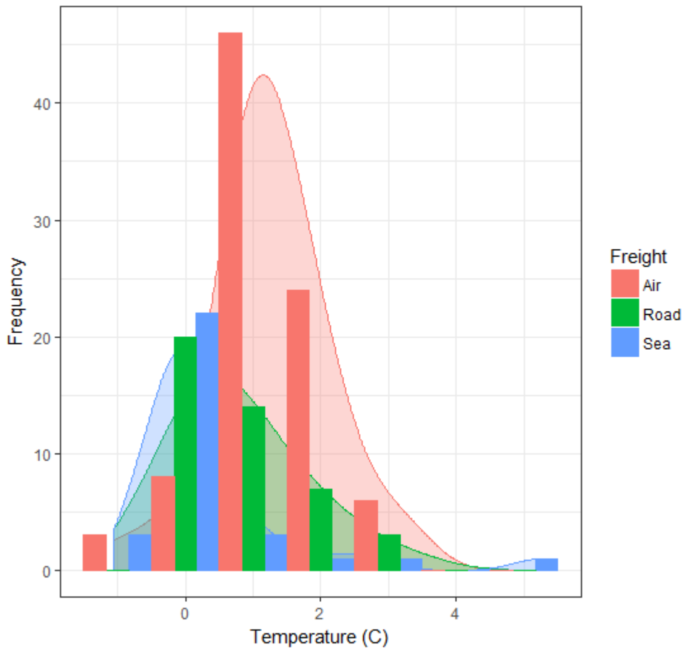


Figure 5: Distribution of average product temperature during transport by air (red), sea (blue) and road (green) freight

[1] P.PSH.1247 – Proof of concept for international cold chain monitoring and automated reporting

There was a clear relationship between the average transport temperature and the predicted shelf-life remaining (Figure 6), even though the relationship will be confounded by the time product took to reach its destination.

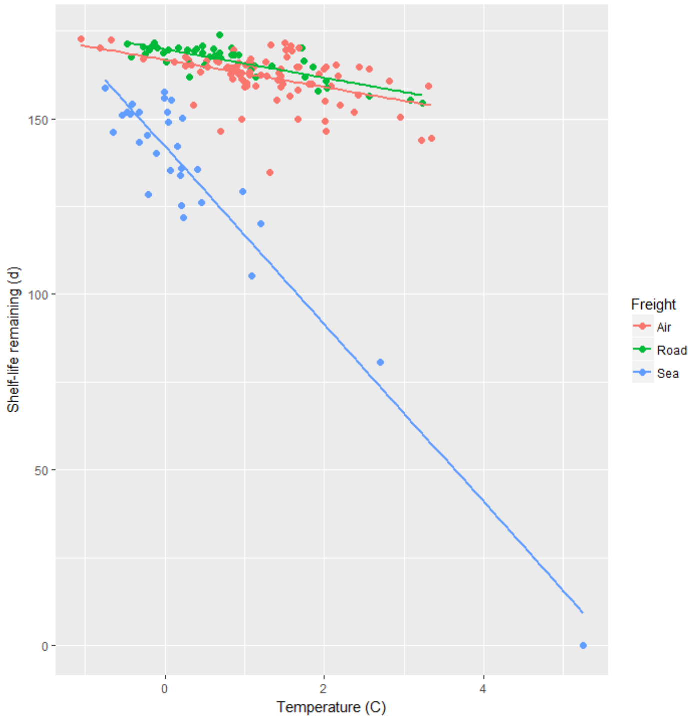


Figure 6: Effect of average transport temperature (°C) on the predicted shelf-life remaining (days) for air, road and sea freight

It is difficult to attribute any improvement in shelf-life remaining because of temperature monitoring during the timeframe of the project (Figure 7). Also, transportation times were not always typical for some markets due to impacts of the pandemic. While there is a general trend upwards in the shelf-life over time this may be due to other factors including more sea freight in the early days of the project.

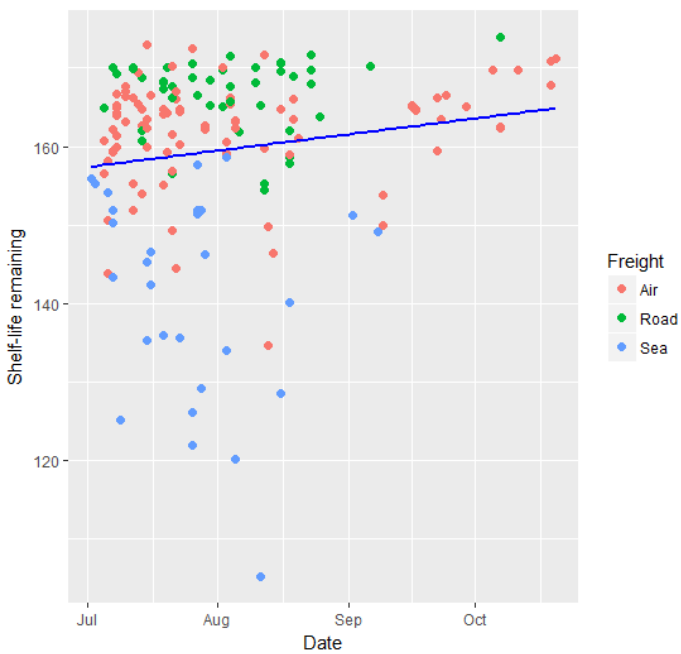


Figure 7: Shelf-life remaining at destination against the initial date of shipping

Looking just at air freight shipments (Figure 8, outliers removed) there is a tendency for less variability and a slight increase in the shelf-life over the duration of the project, although more data is needed to see if this trend is real.

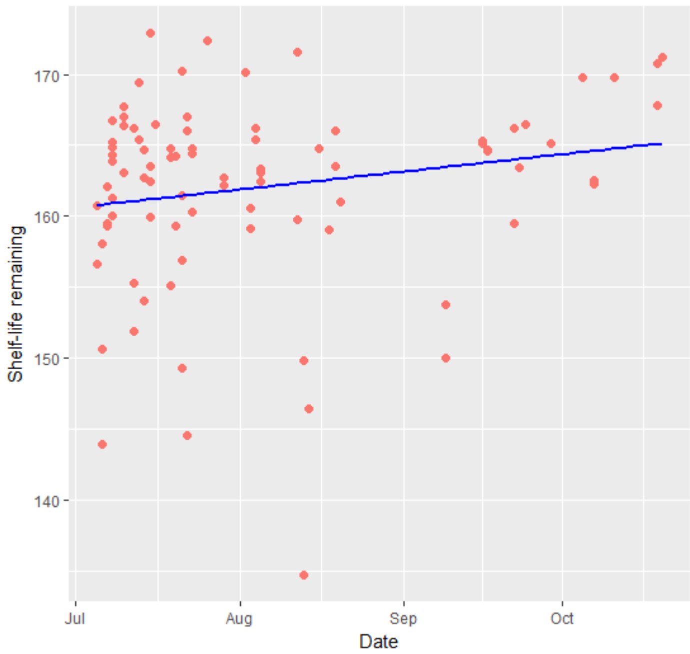


Figure 8: Shelf-life remaining at destination against the initial date of shipping

4.2 Temperature monitoring

Temperature monitoring has been used to inform customers of issues with storage conditions throughout distribution. For example, a domestic customer for MAP mince requested loggers be placed in product shipped to various stores throughout Australia, after issues with product shelf-life. Data was collected over several months and used to determine how transport and handling impacted on the shelf-life of product. It should be noted that the predictive model has not been calibrated for minced product and is likely to overestimate the shelf-life remaining. Nevertheless, the model can be used to give an idea of the relative effect of holding conditions on the shelf-life. In this example (Figure 9) it was found that elevated holding temperatures at destination were dismissed by managers as not significant. However, analysis of the data showed that holding product at 4 °C instead of the recommended -0.5 °C could have a significant impact on the shelf-life remaining (Table 2).

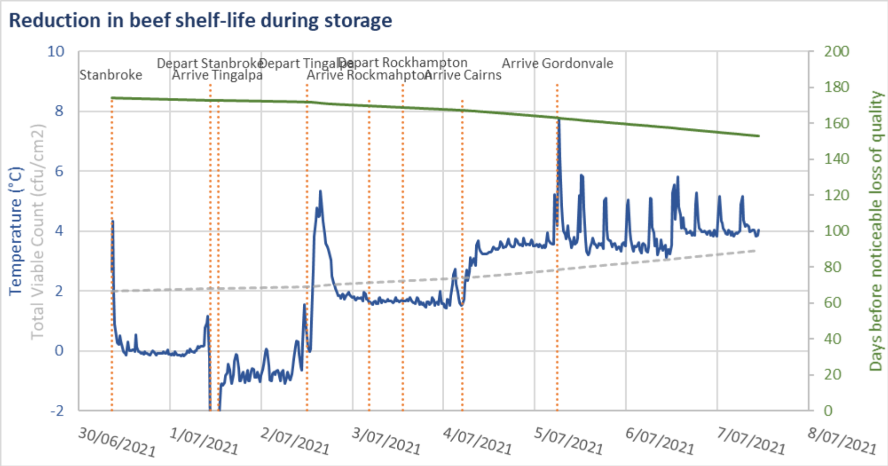


Figure 9: Temperature (blue line) of chilled packaged mince shipped from Processor A (Start) by road to Gordonvale QLD. Solid green line is the shelf-life remaining in days (right hand axis). Broken red lines represent key points in the transport chain as identified by GPS data collected by the logger. The broken grey line is the $\log_{10}$ increase in aerobic plate count.

Table 2: Summary of predicted shelf-life remaining for product when stored at theoretical storage temperatures. Shelf-life remaining calculated from the time product arrived at destination i.e., excluding Gordonvale data.

Storage Temperature (°C)	Shelf-life Remaining (days) [a]	Excluding Gordonvale data (days)
-0.5	153	163
0	121	129
1	80	86
2	58	61
3	43	46
4	34	36

[a] Note shelf-life modelling has not been calibrated for minced product

Processor A through Tive had established a customer portal where tracker data can be accessed on retrieval of the logger from product. This has been useful to both Processor A and customers in discussions around product shelf-life and distribution systems.

4.3 Shock Data

Shock readings were used to identify points in the supply chain where handling may have resulted in a loss of packaging integrity. As an example, a customer had issues with product spoilage. Analysis of the time/temperature data (Figure 10) showed that product was reaching the customer in good condition with around 170 d shelf-life remaining.

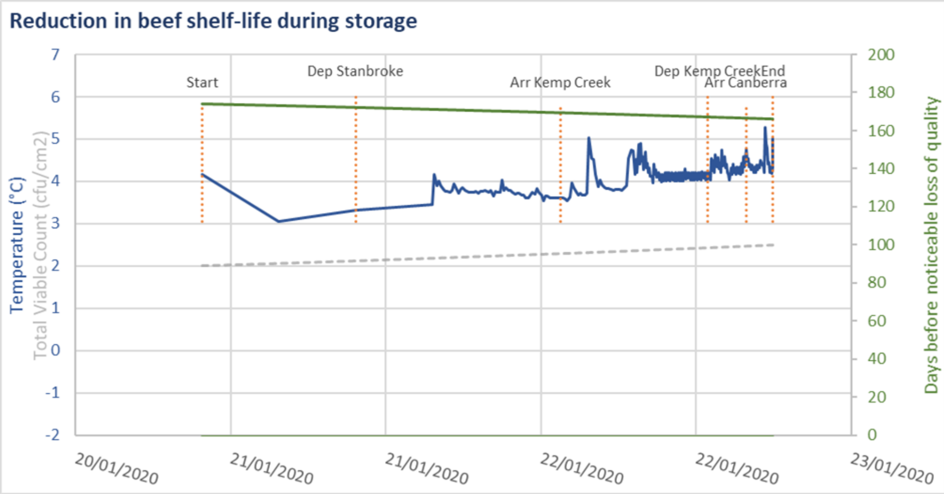


Figure 10: Temperature history of domestic product shipped from Processor A to Canberra. Temperature is given by the blue line while shelf-life remaining (on storage at -0.5 °C) is given by the green line.

Examination of shock data showed significant shock events occurring after product had arrived at destination i.e., at the distribution centre (**Figure *11***). It was likely that poor handling of product at destination resulted in damage to the master pack, compromising the shelf-life of product. This data was used by Processor A to make the customer aware of possible handling issues. The customer requested loggers be placed in product shipped to its multiple distribution centres to map handling issues throughout their system. No problems have been reported since corrective actions were put in place by the customer.

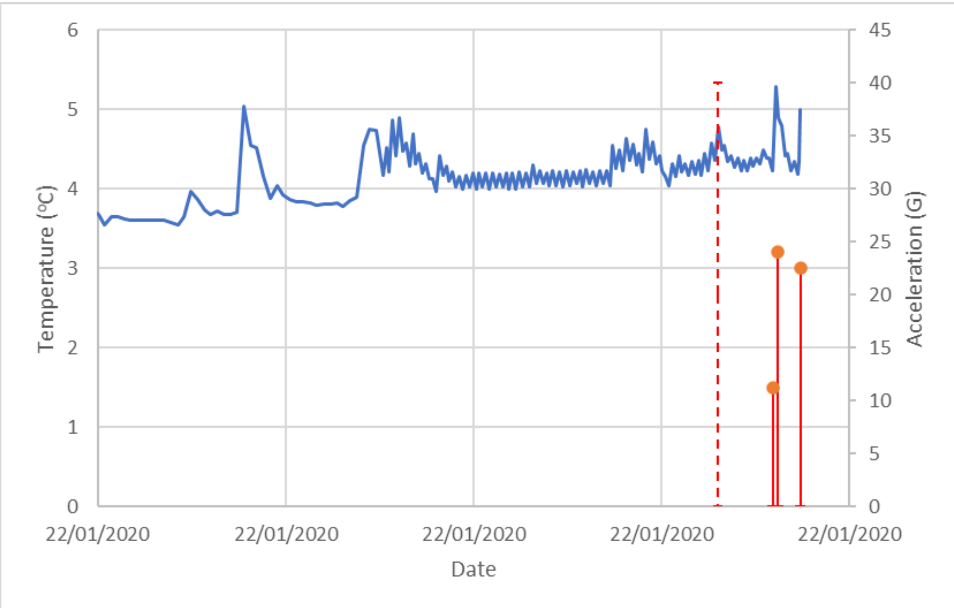


Figure 11: Temperature history (blue line) and significant shock events (red points) for product shipped domestically from Processor A to Canberra. Broken red line is the time product arrived at destination. Data is an extract from the shelf-life analysis plot in Figure 10.

4.4 Shelf-life trial

The temperature history for product stored at Processor A as pat of the shelf-life trial is provided in Figure 12.

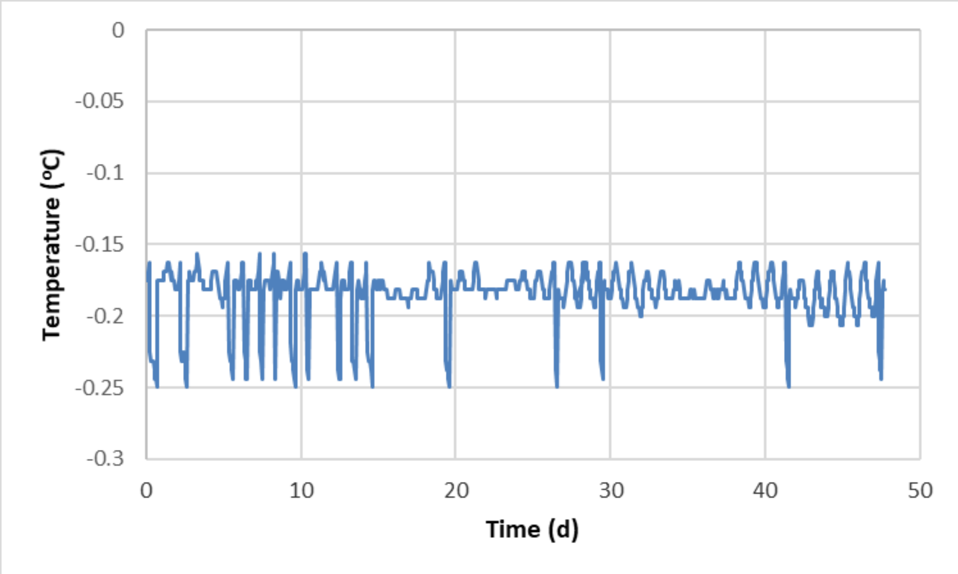


Figure 12: Temperature history of product stored at Processor A as part of the shelf-life study

Temperature data was analysed using the predictive tool to estimate remaining shelf-life of product. In this case, the starting count was known (3.8 Log CFU/cm^2), and this was used in the model rather than the default value of 100 CFU/cm^2. The higher starting count resulted in a lowering in the predicted maximum shelf-life from 174 d to 149 d. There was a drop in predicted shelf-life remaining at the end of storage from 149 to 92 days, a loss of 57 days which is not that much longer than the storage time (48 d) indicating an acceptable (although not optimum) storage temperature. Predicted shelf-life remaining at various storage temperatures is summarised in Table 3.

Table 3: Summary of predicted shelf-life remaining for product at various storage temperatures

Storage Temperature (°C)	Shelf-life Remaining (days) [a]
-0.5	92
0	73
1	49
2	35
3	26
4	20
5	16

As samples in the study were not analysed through to failure it is difficult to use the experimental data to verify the ability of the predictive model to accurately determine the shelf-life of these products. However, the model also predicts the increase in bacterial numbers during storage. Trial samples were analysed for aerobic plate count (APC) making it possible to compare observed counts with those predicted by the model (Figure 13).

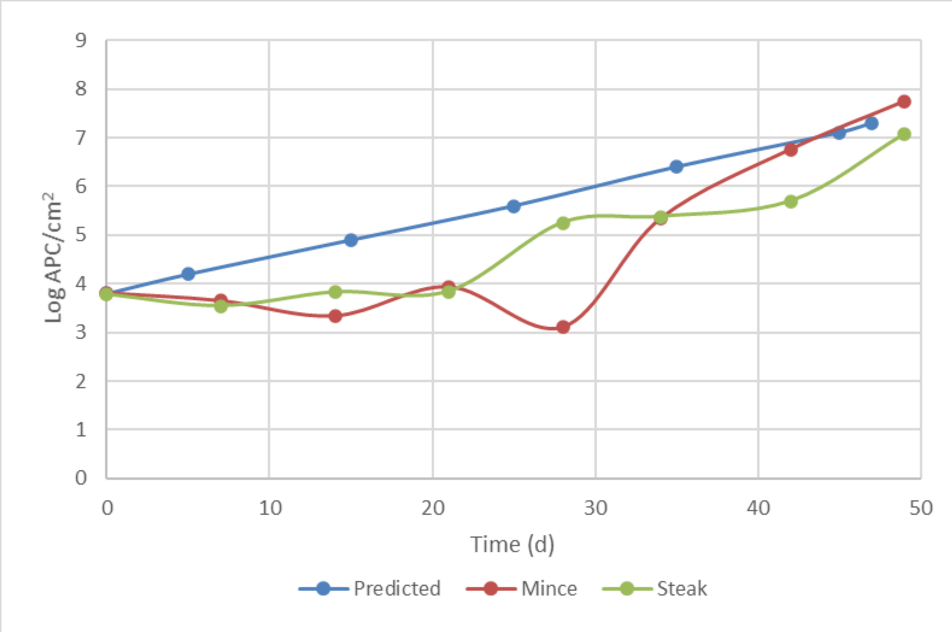


Figure 13: Predicted increase in Aerobic Plate Count (APC; blue line) compared with actual APC counts (flex-pack mince, red line and skin-pack cube roll, green line) found on samples stored as part of the shelf-life study

There was good agreement with predicted counts against those found on product after storage for up to 47 days. How this relates to the predicted shelf-life is not known are requires further investigation.

4.5 Claims on products and impact from logger

The amount of reduction in claims since the trail began has been significant. Prior to implementation of loggers the number of claims total claims has reached 124 and for the general comment of "Temperature abuse" or damaged packaging. However, at completion of this logger implementation, the amount of claim has been reduced to only 2 and the additional benefits of more descriptive claims.

The reduction could be attributed in part with the announcement to partners the logging of devices have started. This was evident with retailer A claims on damaged packaging, in addition, the use of the shelf-life model to highlight the impact on retail display storage of 5°C on product was the main cause of product discolouration for MAP product.

5. Conclusions

The implementation of real-time temperature logging of products shipped to both domestic and international customers was found to be a valuable tool in informing customers and Processor A of potential issues in relation to cold chain management. Real-time incorporation of the University of Tasmania/MLA shelf-life prediction tool would allow Processor A to inform customers of issues may impact on product wholesomeness. Processor A will continue to use the loggers and will implement it for all shipments moving forward from this trial.

5.1 Key findings

- Feedback of temperature history data to a customer resulted in a drop in claims (blown packs) from 22 in 2019 to 17 in 2020 and only 2 in 2021 (at the time of writing this report).
- Temperature monitoring of shipments initiated on behalf of a key client identified problematic areas within their distribution system. Provision of predicted shelf-life data reinforced the criticality of temperature control where it was demonstrated that just a few degrees above ideal resulted in a significant loss in product shelf-life. This information was passed onto managers to reinforce the need for tighter temperature control and to implement corrective actions.
- Real-time logging has removed the issue of having to return loggers to Processor A for analysis. In the past it was found that most loggers were not returned.
- While there is a financial benefit to mapping cold chains the main benefit is in understanding the various customer cold chains and providing customers with confidence in the shelf-life of products. The actual benefits in monetary terms are yet to be fully realised.
- The attributed benefits are only realised when an issue occur, for example pushing back on local delivery company due to poor handling, can save up to $25,000 per case.
- Export customers claims can varied between $125 – $200,000. The occurrence of temperature abuse situation are random, on average industry reported savings on claims can be up to $600,000 per annum.
- Incorporation of the shelf-life tool into the TIVE platform would allow Processor A to rapidly inform customers of the impact of cold chain management decisions on product shelf-life.

5.2 Benefits to industry

Real-time temperature monitoring in conjunction with shelf-life prediction will allow industry to discuss cold chain issues with customers avoiding costly claims and providing customers with confidence in the shelf-life of product on arrival.

6. Future research and recommendations

- Tive to setup a portal where customers can download logger data in real-time to allow management to make informed decisions on product suitability based on temperature history and predicted shelf-life data.
- Verification of the ability of the shelf-life model to accurately predict remaining shelf-life for mince and retail-ready packs.
- Develop method for automated logger registration via barcode scanning.

7. References

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ISO 21528-2: 2017. Microbiology of the food chain - Horizontal method for the detection and enumeration of Enterobacteriaceae-Part 2: Colony-count technique.

ISO 17025: 2017. General Requirements for the Competence of Testing and Calibration Laboratories.

8. Appendix 1: Summary of shelf-life calculations for international and domestic shipments of chilled beef

Destination	Start Date	Arrival in destination country	Freight	Days to destination country [1]	Ave. Temp	Rate of Days Lost [2]	SLR [3] -0.5°C	SLR +2°C	SLR +4°C	Days in destination country [4]	Ave. Temp (°C) in destination country	Rate of Days Lost in country
China	7/07/2021	12/07/2021	Air	5.3	1.45	2.31	162.1	45.7	35.5	1.5	5.68	6.93
China	7/07/2021	2/08/2021	Sea	26.2	-0.33	1.18	143.3	40.4	31.4	6.8	-0.46	1.05
China	12/07/2021	19/07/2021	Air	7.1	2.37	3.16	151.9	42.8	33.3	15.2	2.41	3.81
China	16/08/2021	21/09/2021	Sea	35.8	-0.21	1.28	128.6	36.2	28.2	5.2	0.27	1.47
Domestic	20/07/2021	21/07/2021	Road	1.7	1.72	2.48	170.1	47.9	37.3	3.4	2.32	2.94
Domestic	27/07/2021	30/07/2021	Road	2.9	1.74	2.59	166.6	46.9	36.5	0.1	4.94	5.97
Domestic	10/08/2021	12/08/2021	Road	2.4	0.61	1.73	170.0	47.9	37.2	0.5	2.30	2.92
Domestic	2/08/2021	6/08/2021	Road	3.8	-0.20	1.20	169.7	47.8	37.2	1.4	1.71	2.79
Domestic	2/08/2021	6/08/2021	Road	4.1	1.34	2.22	165.1	46.5	36.2	2.7	1.10	1.97
Domestic	18/08/2021	24/08/2021	Road	6.0	1.92	2.75	157.9	44.5	34.6	0.0		
Domestic	18/08/2021	23/08/2021	Road	5.5	2.03	2.85	158.7	44.7	34.8	0.4	4.70	5.35
Domestic	16/08/2021	18/08/2021	Road	2.0	0.47	1.76	170.7	48.1	37.4	0.2	1.15	2.02
Domestic	16/08/2021	19/08/2021	Road	3.2	0.28	1.46	169.6	47.8	37.1	1.8	2.38	3.00
Domestic	6/08/2021	15/08/2021	Road	8.5	0.31	1.47	161.8	45.6	35.4	1.3	2.80	3.41
Domestic	12/08/2021	17/08/2021	Road	5.0	3.08	3.77	155.3	43.7	34.0	1.0	2.60	3.24
Domestic	12/08/2021	17/08/2021	Road	5.0	3.23	3.94	154.4	43.5	33.8	1.0	2.33	2.95
Domestic	10/08/2021	13/08/2021	Road	3.3	0.84	1.82	168.2	47.4	36.8	0.8	2.04	2.69
Domestic	4/08/2021	6/08/2021	Road	2.0	-0.48	1.36	171.5	48.3	37.6	0.8	1.87	2.57
Domestic	4/08/2021	10/08/2021	Road	5.7	0.30	1.49	165.7	46.7	36.3	1.4	1.58	2.34
Domestic	4/08/2021	8/08/2021	Road	3.9	0.56	1.68	167.7	47.2	36.7	3.2	2.03	2.72
Domestic	19/08/2021	22/08/2021	Road	3.0	0.47	1.78	168.9	47.6	37.0	8.8	0.02	1.32
Domestic	25/08/2021	30/08/2021	Road	5.3	1.07	1.99	163.8	46.1	35.9	6.7	3.09	3.66
Domestic	23/08/2021	25/08/2021	Road	2.0	-0.13	1.28	171.6	48.3	37.6	0.7	0.72	1.72

Destination	Start Date	Arrival in destination country	Freight	Days to destination country [1]	Ave. Temp	Rate of Days Lost [2]	SLR [3] -0.5°C	SLR +2°C	SLR +4°C	Days in destination country [4]	Ave. Temp (°C) in destination country	Rate of Days Lost in country
Domestic	23/08/2021	26/08/2021	Road	3.6	0.62	1.73	167.9	47.3	36.8	1.4	3.20	3.79
Domestic	23/08/2021	26/08/2021	Road	3.1	0.04	1.45	169.7	47.8	37.2	0.8	1.59	2.40
Domestic	18/08/2021	24/08/2021	Road	5.8	1.14	2.13	162.0	45.6	35.5	0.9	1.78	2.49
Domestic	16/08/2021	19/08/2021	Road	2.9	-0.17	1.27	170.6	48.0	37.4	1.9	1.26	2.23
Domestic	7/10/2021	7/10/2021	Road	0.2	0.69	1.81	173.9	49.0	38.1	0.0	-0.19	1.16
Domestic	6/09/2021	9/09/2021	Road	3.1	-0.10	1.31	170.2	48.0	37.3	7.8	2.61	3.21
Domestic	5/07/2021	8/07/2021	Road	3.4	1.86	2.73	164.9	46.4	36.1	0.4	1.94	2.67
Domestic	19/07/2021	22/07/2021	Road	3.1	0.93	2.01	168.1	47.3	36.8	0.0	5.21	5.97
Domestic	12/07/2021	15/07/2021	Road	2.9	0.17	1.42	170.1	47.9	37.3	0.0	0.65	2.37
Domestic	21/07/2021	26/07/2021	Road	5.0	2.56	3.59	156.5	44.1	34.3	3.2	3.87	4.44
Domestic	14/07/2021	19/07/2021	Road	4.7	2.02	2.86	160.8	45.3	35.2	0.0	3.40	3.94
Domestic	7/07/2021	9/07/2021	Road	2.2	0.83	1.87	170.1	47.9	37.3	10.7	2.67	3.46
Domestic	19/07/2021	22/07/2021	Road	3.1	0.87	1.90	168.3	47.4	36.9	1.8	2.57	3.18
Domestic	14/07/2021	19/07/2021	Road	4.8	1.75	2.57	162.0	45.6	35.5	2.2	6.25	7.47
Domestic	12/07/2021	15/07/2021	Road	2.8	0.40	1.55	169.9	47.9	37.2	0.9	2.67	3.27
Domestic	21/07/2021	27/07/2021	Road	6.1	0.01	1.31	166.2	46.8	36.4	0.1	3.12	3.99
Domestic	19/07/2021	23/07/2021	Road	3.9	0.70	1.76	167.4	47.2	36.7	0.2	2.87	3.52
Domestic	14/07/2021	17/07/2021	Road	2.9	0.68	1.90	168.7	47.5	37.0	1.9	1.42	2.25
Domestic	21/07/2021	27/07/2021	Road	6.2	-0.42	1.05	167.7	47.2	36.7	1.8	1.05	1.98
Domestic	26/07/2021	30/07/2021	Road	4.1	-0.02	1.35	168.7	47.5	37.0	1.9	3.88	4.44
Domestic	26/07/2021	29/07/2021	Road	3.2	-0.28	1.13	170.6	48.1	37.4	0.0	4.61	5.25
Domestic	8/07/2021	11/07/2021	Road	3.3	0.37	1.53	169.3	47.7	37.1	1.0	2.43	3.03
Domestic	11/08/2021	15/08/2021	Road	4.4	1.13	2.08	165.2	46.5	36.2	0.3	2.67	3.26
Domestic	30/07/2021	5/08/2021	Road	5.5	0.50	1.63	165.3	46.6	36.2	3.5	0.93	1.87
Domestic	30/07/2021	4/08/2021	Road	5.1	-0.25	1.15	168.4	47.4	36.9	13.1	-0.43	1.04
Domestic	27/07/2021	9/08/2021	Sea	12.7	-0.01	1.30	157.7	44.4	34.5	13.4	-0.12	1.21
Hong Kong	14/07/2021	21/07/2021	Air	7.0	2.20	2.89	154.0	43.4	33.7	11.0	3.15	3.78

Destination	Start Date	Arrival in destination country	Freight	Days to destination country [1]	Ave. Temp	Rate of Days Lost [2]	SLR [3] -0.5°C	SLR +2°C	SLR +4°C	Days in destination country [4]	Ave. Temp (°C) in destination country	Rate of Days Lost in country
Hong Kong	21/07/2021	28/07/2021	Air	7.0	0.85	1.83	161.5	45.5	35.4	1.5	4.45	5.43
Hong Kong	15/07/2021	16/07/2021	Air	1.2	-1.06	1.13	172.9	48.7	37.9	0.1	4.84	5.84
Hong Kong	26/07/2021	28/07/2021	Air	1.9	-0.68	0.95	172.4	48.6	37.8	4.2	2.54	3.21
Hong Kong	8/07/2021	14/07/2021	Air	5.9	0.53	1.59	164.9	46.5	36.1	0.4	3.56	4.27
Hong Kong	7/07/2021	14/07/2021	Air	7.1	1.14	2.12	159.3	44.9	34.9	0.4	6.28	7.62
Hong Kong	10/07/2021	14/07/2021	Air	3.9	1.06	1.99	166.4	46.9	36.5	0.6	4.08	4.98
Hong Kong	6/07/2021	14/07/2021	Air	7.9	3.22	3.86	143.9	40.5	31.5	0.6	4.64	5.42
Hong Kong	8/07/2021	14/07/2021	Air	5.7	0.85	1.83	163.9	46.2	35.9	14.7	0.12	1.39
Hong Kong	19/07/2021	23/07/2021	Air	3.8	1.68	2.46	164.8	46.4	36.1	6.2	5.23	6.23
Hong Kong	15/07/2021	21/07/2021	Air	5.7	1.81	2.54	159.9	45.0	35.0	10.3	2.95	3.52
Hong Kong	15/07/2021	21/07/2021	Air	5.8	0.92	1.87	163.5	46.1	35.8	7.0	1.12	2.15
Hong Kong	23/07/2021	28/07/2021	Air	5.3	0.78	1.77	164.8	46.4	36.1	5.8	2.95	3.53
Hong Kong	3/08/2021	11/08/2021	Air	7.6	1.00	1.99	159.1	44.8	34.9	4.2	2.66	3.72
Hong Kong	22/07/2021	26/07/2021	Air	3.6	1.07	1.99	167.0	47.1	36.6	15.6	1.95	2.73
Hong Kong	3/08/2021	10/08/2021	Air	7.1	1.00	1.93	160.6	45.2	35.2	3.1	3.96	4.58
Hong Kong	5/08/2021	31/08/2021	Sea	26.3	1.20	2.06	120.1	33.8	26.3	1.5	1.21	2.05
Hong Kong	16/08/2021	18/08/2021	Air	2.3	2.44	4.21	164.8	46.4	36.1	13.0	2.72	3.33
Hong Kong	20/08/2021	25/08/2021	Air	5.1	1.42	2.58	161.0	45.3	35.3	6.3	3.96	4.64
Hong Kong	5/08/2021	11/08/2021	Air	6.0	1.06	1.98	162.4	45.8	35.6	14.4	3.10	3.65
Hong Kong	13/08/2021	26/08/2021	Air	12.9	0.96	1.90	149.8	42.2	32.8	8.9	0.74	1.77
Hong Kong	5/08/2021	11/08/2021	Air	5.8	0.96	1.92	163.1	45.9	35.7	6.4	3.66	4.27
Hong Kong	18/08/2021	25/08/2021	Air	6.8	1.45	2.26	159.0	44.8	34.8	13.4	2.57	3.21
Hong Kong	8/07/2021	15/07/2021	Air	6.9	0.96	1.89	161.3	45.4	35.3	0.5	4.87	5.64
Hong Kong	5/08/2021	12/08/2021	Air	7.0	0.45	1.56	163.3	46.0	35.8	27.4	0.30	1.46
Hong Kong	15/07/2021	21/07/2021	Air	5.7	1.20	2.09	162.4	45.7	35.6	14.5	3.21	4.26
Hong Kong	2/08/2021	4/08/2021	Air	1.7	1.68	2.42	170.1	47.9	37.3	18.0	1.86	2.60
Hong Kong	11/10/2021	13/10/2021	Air	1.8	1.52	2.43	169.8	47.8	37.2	0.2	4.43	5.04

Destination	Start Date	Arrival in destination country	Freight	Days to destination country [1]	Ave. Temp	Rate of Days Lost [2]	SLR [3] -0.5°C	SLR +2°C	SLR +4°C	Days in destination country [4]	Ave. Temp (°C) in destination country	Rate of Days Lost in country
Hong Kong	20/10/2021	21/10/2021	Air	1.4	1.33	2.20	171.2	48.2	37.5	1.0	3.17	3.75
Hong Kong	22/09/2021	27/09/2021	Air	4.7	0.67	1.70	166.2	46.8	36.4	1.8	2.58	3.16
Hong Kong	22/09/2021	29/09/2021	Air	6.7	1.02	2.19	159.5	44.9	34.9	0.9	6.20	7.72
Hong Kong	23/09/2021	29/09/2021	Air	5.5	1.06	2.00	163.4	46.0	35.8	1.2	4.97	5.70
Hong Kong	5/10/2021	7/10/2021	Air	2.4	0.86	1.87	169.8	47.8	37.2	0.8	3.62	4.26
Indonesia	20/07/2021	24/07/2021	Air	3.8	3.31	3.93	159.3	44.9	34.9	2.7	3.44	5.53
Japan	3/07/2021	17/07/2021	Sea	14.0	0.08	1.35	155.3	43.7	34.0	3.1	0.54	1.83
Japan	10/07/2021	15/07/2021	Air	5.2	-0.27	1.41	167.0	47.0	36.6	26.3	-0.66	1.00
Japan	6/07/2021	26/07/2021	Sea	20.2	2.70	4.63	80.8	22.8	17.7	10.1	1.70	2.56
Japan	15/07/2021	8/08/2021	Sea	24.2	-0.22	1.20	145.2	40.9	31.8	3.1	0.20	1.57
Japan	16/07/2021	8/08/2021	Sea	23.2	0.16	1.38	142.3	40.1	31.2	2.0	0.36	1.51
Japan	11/08/2021	14/09/2021	Sea	34.1	1.09	2.02	105.2	29.6	23.0	0.0		
Japan	5/07/2021	26/07/2021	Sea	21.1	5.25	8.41	0.0	0.0	0.0	1.8	16.03	27.74
Japan	29/07/2021	29/08/2021	Sea	30.3	-0.65	0.93	146.2	41.2	32.0	2.7	-0.58	1.00
Malaysia	13/07/2021	15/07/2021	Air	2.0	1.59	2.48	169.4	47.7	37.1	14.3	0.04	1.40
Malaysia	19/07/2021	23/07/2021	Air	3.6	2.00	2.79	164.1	46.2	35.9	4.1	2.74	4.06
Malaysia	20/07/2021	23/07/2021	Air	3.2	2.56	3.20	164.2	46.2	36.0	1.3	4.85	6.66
Malaysia	19/07/2021	15/08/2021	Sea	27.4	0.20	1.40	135.9	38.3	29.8	1.5	4.00	4.64
Malaysia	19/07/2021	23/07/2021	Air	3.8	1.65	2.46	164.8	46.4	36.1	1.1	4.95	5.85
Malaysia	3/08/2021	20/08/2021	Sea	17.0	-0.75	0.91	158.7	44.7	34.8	1.0	-0.05	1.43
Malaysia	5/07/2021	9/07/2021	Air	3.8	2.82	3.56	160.7	45.3	35.2	26.0	0.48	1.59
Malaysia	12/07/2021	16/07/2021	Air	3.7	1.26	2.18	166.2	46.8	36.4	0.2	2.28	3.01
Malaysia	13/08/2021	31/08/2021	Air	18.2	1.31	2.18	134.7	38.0	29.5	22.8	3.86	4.46
Malaysia	7/10/2021	11/10/2021	Air	4.2	2.17	2.87	162.3	45.7	35.5	0.1	5.31	6.25
Netherlands	21/07/2021	26/07/2021	Air	5.6	2.43	3.07	156.9	44.2	34.4	1.8	5.50	6.53
NZ	7/07/2021	24/07/2021	Sea	16.8	0.03	1.33	151.9	42.8	33.3	8.1	-0.28	1.12
NZ	7/07/2021	24/07/2021	Sea	16.7	0.22	1.43	150.3	42.3	32.9	7.8	-0.06	1.24

Destination	Start Date	Arrival in destination country	Freight	Days to destination country [1]	Ave. Temp	Rate of Days Lost [2]	SLR [3] -0.5°C	SLR +2°C	SLR +4°C	Days in destination country [4]	Ave. Temp (°C) in destination country	Rate of Days Lost in country
NZ	26/07/2021	23/08/2021	Sea	28.3	0.46	1.70	126.1	35.5	27.6	2.1	0.00	1.29
Qatar	9/09/2021	19/09/2021	Air	9.9	1.67	2.46	150.0	42.2	32.8	0.9	2.07	2.80
Qatar	16/07/2021	26/07/2021	Sea	10.0	2.02	2.76	146.5	41.3	32.1	5.9	2.92	3.64
Qatar	19/07/2021	26/07/2021	Air	7.1	2.01	2.71	155.1	43.7	34.0	8.5	2.47	3.13
Qatar	14/08/2021	29/08/2021	Air	15.1	0.70	1.85	146.4	41.3	32.1	0.5	-0.27	1.25
Saudi Arabia	21/07/2021	30/07/2021	Air	8.9	2.01	2.81	149.3	42.1	32.7	17.9	3.90	4.85
Singapore	8/09/2021	27/09/2021	Sea	19.1	0.04	1.32	149.1	42.0	32.6	3.8	0.60	1.82
Singapore	2/09/2021	25/09/2021	Sea	23.0	-0.54	1.00	151.2	42.6	33.1	2.9	-0.41	1.10
Singapore	5/07/2021	12/07/2021	Air	7.3	1.57	2.42	156.6	44.1	34.3	0.9	-2.23	1.94
Singapore	6/07/2021	12/07/2021	Air	6.4	2.96	3.69	150.6	42.4	33.0	0.3	5.52	6.40
Singapore	7/07/2021	12/07/2021	Air	5.3	2.09	2.77	159.5	44.9	34.9	1.0	5.39	6.48
Singapore	10/07/2021	15/07/2021	Air	4.8	1.43	2.32	163.1	46.0	35.7	0.6	5.92	7.32
Singapore	8/07/2021	14/07/2021	Air	6.2	1.48	2.32	160.0	45.1	35.0	0.3	5.24	6.06
Singapore	8/07/2021	12/07/2021	Air	4.6	1.09	1.99	165.2	46.5	36.2	9.5	2.45	3.28
Singapore	6/07/2021	12/07/2021	Air	6.5	1.67	2.47	158.1	44.5	34.6	1.6	1.12	2.25
Singapore	22/07/2021	26/07/2021	Air	4.3	0.92	1.91	166.0	46.8	36.4	4.5	2.20	2.89
Singapore	12/07/2021	20/07/2021	Air	8.3	1.40	2.29	155.3	43.8	34.0	1.6	2.66	3.49
Singapore	8/07/2021	12/07/2021	Air	4.4	1.45	2.25	164.3	46.3	36.0	9.5	1.55	2.41
Singapore	16/07/2021	20/07/2021	Air	4.6	0.65	1.68	166.5	46.9	36.5	8.5	1.66	2.42
Singapore	23/07/2021	28/07/2021	Air	5.5	0.83	1.79	164.4	46.3	36.0	0.7	2.27	2.92
Singapore	23/07/2021	17/08/2021	Sea	25.2	0.41	1.53	135.6	38.2	29.7	1.1	1.52	2.44
Singapore	29/07/2021	2/08/2021	Air	4.4	1.93	2.62	162.7	45.8	35.6	17.3	1.49	2.32
Singapore	23/07/2021	30/07/2021	Air	6.9	1.03	2.01	160.3	45.2	35.1	4.5	3.18	3.79
Singapore	19/08/2021	25/08/2021	Air	5.8	0.90	1.85	163.5	46.1	35.8	5.2	1.22	2.22
Singapore	19/08/2021	23/08/2021	Air	4.2	1.07	1.97	166.0	46.8	36.4	6.7	1.73	2.45
Singapore	12/08/2021	13/08/2021	Air	1.2	1.50	2.29	171.6	48.3	37.6	2.8	1.66	2.53
Singapore	18/08/2021	15/09/2021	Sea	28.2	-0.11	1.21	140.1	39.5	30.7	3.0	0.35	1.48

Destination	Start Date	Arrival in destination country	Freight	Days to destination country [1]	Ave. Temp	Rate of Days Lost [2]	SLR [3] -0.5°C	SLR +2°C	SLR +4°C	Days in destination country [4]	Ave. Temp (°C) in destination country	Rate of Days Lost in country
Singapore	13/07/2021	16/07/2021	Air	3.1	2.15	2.86	165.4	46.6	36.2	17.9	2.88	3.48
Singapore	27/07/2021	18/08/2021	Sea	21.6	-0.47	1.03	151.9	42.8	33.3	5.4	-0.78	0.87
Singapore	27/07/2021	17/08/2021	Sea	21.3	-0.44	1.07	151.4	42.6	33.2	5.6	-0.45	1.03
Singapore	19/10/2021	21/10/2021	Air	1.5	1.58	2.33	170.8	48.1	37.4	1.5	1.88	2.57
Singapore	7/10/2021	13/10/2021	Air	6.1	0.94	1.93	162.5	45.8	35.6	0.5	3.00	3.57
Singapore	24/09/2021	29/09/2021	Air	4.8	0.52	1.61	166.5	46.9	36.5	6.3	1.78	2.50
Singapore	19/10/2021	22/10/2021	Air	2.8	1.53	2.30	167.8	47.3	36.8	0.8	2.79	3.60
Singapore	9/09/2021	23/09/2021	Air	13.6	0.35	1.50	153.8	43.3	33.7	18.8	1.67	2.50
Singapore	17/09/2021	22/09/2021	Air	4.6	1.11	2.09	164.7	46.4	36.1	1.3	3.47	4.13
Singapore	17/09/2021	22/09/2021	Air	5.4	0.77	1.78	164.6	46.4	36.0	11.6	-0.36	1.15
South Korea	6/07/2021	24/07/2021	Sea	17.7	-0.41	1.14	154.2	43.4	33.8	3.1	1.44	2.93
South Korea	28/07/2021	15/08/2021	Sea	18.0	-0.33	1.25	151.8	42.8	33.2	3.1	0.30	1.82
South Korea	15/07/2021	13/08/2021	Sea	29.0	0.07	1.34	135.3	38.1	29.6	2.6	0.15	1.39
South Korea	26/07/2021	31/08/2021	Sea	36.1	0.23	1.45	122.0	34.4	26.7	2.9	0.69	1.80
South Korea	3/08/2021	1/09/2021	Sea	28.7	0.19	1.40	134.0	37.8	29.4	1.5	2.86	3.75
Taiwan	8/07/2021	13/07/2021	Air	5.1	0.29	1.47	166.7	46.9	36.5	1.8	4.90	5.81
Taiwan	21/07/2021	26/07/2021	Air	4.6	-0.82	0.87	170.2	47.9	37.3	2.9	2.67	3.82
Taiwan	4/08/2021	10/08/2021	Air	5.8	0.33	1.53	165.4	46.6	36.2	0.0		
Taiwan	4/08/2021	10/08/2021	Air	5.8	0.12	1.41	166.2	46.8	36.4	0.0		
Taiwan	28/07/2021	21/08/2021	Sea	23.5	0.97	1.91	129.2	36.4	28.3	18.6	1.55	2.48
Taiwan	16/09/2021	21/09/2021	Air	4.6	1.01	1.96	165.3	46.6	36.2	1.2	2.91	4.04
Taiwan	16/09/2021	21/09/2021	Air	4.8	0.90	1.90	165.1	46.5	36.2	1.1	2.89	3.94
Thailand	2/07/2021	16/07/2021	Sea	14.1	-0.01	1.31	155.9	43.9	34.1	6.0	0.24	1.54
UAE	22/07/2021	29/07/2021	Air	7.1	3.35	4.18	144.5	40.7	31.6	5.9	5.50	6.42
UAE	9/07/2021	13/08/2021	Sea	34.5	0.20	1.42	125.2	35.3	27.4	0.5	1.73	2.67
UAE	14/07/2021	17/07/2021	Air	3.1	2.02	3.11	164.7	46.4	36.1	0.0	8.89	11.39
USA	14/07/2021	21/07/2021	Air	6.5	0.82	1.78	162.7	45.8	35.6	9.0	0.66	1.72

Destination	Start Date	Arrival in destination country	Freight	Days to destination country [1]	Ave. Temp	Rate of Days Lost [2]	SLR [3] -0.5°C	SLR +2°C	SLR +4°C	Days in destination country [4]	Ave. Temp (°C) in destination country	Rate of Days Lost in country
USA	29/07/2021	4/08/2021	Air	5.6	1.28	2.14	16.2	45.7	35.5	9.4	0.29	1.60
USA	12/08/2021	18/08/2021	Air	5.6	1.84	2.60	159.8	45.0	35.0	2.9	2.77	3.85
USA	29/09/2021	6/10/2021	Air	6.4	0.25	1.43	165.1	46.5	36.2	1.0	1.99	2.67
Vietnam	10/07/2021	14/07/2021	Air	4.2	0.26	1.57	167.7	47.2	36.7	3.6	3.36	4.02

[1] Time in days between the start of logging and arrival at the final customer (final destination country for international shipments)

[2] The rate at which the shelf-life is reducing during transport. A value of 1 indicates that product is being stored under ideal conditions i.e., at -0.5 °C (the closer the rate is to 1 the better).

[3] The predicted shelf-life remaining on arrival at the destination if product is subsequently stored at -0.5 °C (ideal), 2 °C or 4 °C.

[4] The time in days that loggers continued to record product temperature after arrival at the destination. It is not clear when loggers were removed from product.