COLD CHAIN PERFORMANCE ISSUES NOW AND IN THE FUTURE

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ABSTRACT

The cold chain remains one of the most important ways to preserve perishables and deliver them to market in good condition. The various requirements for success in the cold chain are identified, and examples of what can go wrong are given. Environmental issues are considered. Solutions for the future relating to produce, equipment, stowage and handling, and logistics are identified. The main requirements are for education and training and for provision of good operating systems.

1. INTRODUCTION

The cold chain is generally considered as the transport and storage chain between the initial production and the final consumer of temperature-controlled perishable goods. This is not a complete definition, as there are other items carried under temperature control, for example works of art. For the purposes of this paper, only the transport and storage of perishable foodstuffs and pharmaceuticals will be considered.

There are many types of cold chain. They may be categorised by carriage mode, by commodity, or by location and duration of transport. Table 1 indicates a possible categorization, with "Y" indicating the major applications.

Table 1. Major cold chain categories

	MODE	OF	TRANSPORT			
	Air	Sea Container	Sea Reefer ship	Land International	Land Local Developing countries	Land Local Developed countries
COMMODITY						
FROZEN bulk		Y	Y	Y		
FROZEN retail		Y		Y	Y	Y
CHILLED bulk	Y	Y	Y	Y	Y	Y
CHILLED retail	Y	Y		Y	Y	Y
CHILLED pharmaceutical	Y	Y		Y	Y	Y

Air freight is generally limited to goods at chilled or ambient temperatures. Sea containers are universal in their application. Refrigerated ships carry bulk commodities in their holds, though increasingly these ships also carry containers. International land transport by road and/or rail is able to carry anything. Local distribution generally excludes the movement of bulk frozen goods.

At the present time there are approximately 1300 specialised refrigerated cargo ships, 80,000 refrigerated railcars, 650,000 refrigerated containers and 1.2 million refrigerated trucks in use world-wide (UNEP, 2002 and author's estimates). They carry vast amounts of foodstuffs and other perishables, and mostly do so very successfully.

Storage is an important part of the overall cold chain. It has been reported by one company that, in the transport of pharmaceuticals during the last five years, critical or major problems arising in storage are more than four times as frequent as problems arising in transport (Taylor, 2005). This emphasizes the point that cold chains should always be considered as a whole if reliable results are to be obtained.

2. COLD CHAIN REQUIREMENTS FOR SUCCESS

There are many requirements which have to be met for successful handling of perishables. Some of these are as follows.

2.1 Produce temperatures

All refrigerated produce deteriorates with time at a rate dependent on the temperature of storage. For most frozen goods at normal storage temperatures of -18°C or below, maximum times for high quality storage are appreciably longer than transport times, so there are no special difficulties. Frozen fish requires lower temperatures to achieve this situation.

Refrigerated chilled and fresh produce, stored and transported at temperatures between -1.5°C and +14°C dependent on produce type, frequently has a high quality storage life measured in weeks rather than months, and the relatively slow pace of marine transport frequently requires much closer control of temperature than is achieved in road, rail or air transport if goods are to be carried successfully. Data on storage lives and temperatures show that produce such as oranges and apples are readily transportable by sea, whereas a very short life produce such as watercress could not survive more than a very short sea journey. Many subtropical fruits have lives comparable to the length of time needed to transport them by sea from growing areas to major markets, so special attention to quality of both produce and handling is essential for successful marketing.

Many types of chilled and fresh produce have lower temperature limits below which they are damaged. Clearly, for items carried near their freezing points, lower temperatures will give freezing damage, and this is as true for chilled meats as for other more obvious products. For many fruits, there are temperatures well above their freezing points at which low temperature physiological injuries occur.

There is a temptation if cargoes are loaded at a high temperature to reduce cargo space temperatures to below carriage temperature to achieve more rapid cooling. This can only be done at the risk of damaging part of the cargo.

It must be remembered that, for many cargoes, safe carriage temperatures depend on the variety as well as the type of produce, and may also depend on growing area and on whether early, main, or late harvested produce is being carried. Also, it may be necessary to mix produce with slightly different temperature requirements, in which case the highest temperature must be chosen, with consequent effects on the storage life of the products requiring lower temperatures.

It is essential that the storage characteristics and optimal storage temperature are correctly specified and maintained. Specification is the responsibility of the shipper; temperature maintenance is the responsibility of the carrier. If the shipper specifies the wrong temperature in an obvious way, the

carrier will question it, but in less obvious cases the shipper has no reason to over-ride the instructions given. The carriage instructions must be clear and unambiguous.

2.2 Transport equipment

It is essential to use equipment which can do the job. The correct equipment will have good insulation, good temperature control, adequate airflow and refrigeration capacity, and will be well maintained. It will be able to achieve all that is requested in the carriage instructions. In the case of refrigerated containers, it should have been subject to a pre-trip inspection not longer than a month before loading.

The operation of transport refrigeration in ships' holds, in containers, and in trucks differs, and the shipper would be well advised to be familiar with the equipment to be used. As a rule of thumb, ships should be most reliable because of the size of cargoes they carry, and road vehicles may be most liable to failure as they carry out many journeys often on bad road surfaces.

2.3 Produce quality

At best, refrigerated transport can maintain quality, it cannot improve it. Poor quality produce cannot justify the costs of transportation, and can give the likelihood of an unsuccessful outturn, leading to loss of confidence in the producer. Long distance transportation should be seen as a means of obtaining premium prices for top quality produce, and never as a means of disposing of second-rate goods for which no local market exists.

The quality of produce may be subject to standards and inspections by producer boards or export control boards in the country of origin. It may also be subject to import requirements in the receiving country, details of which must be determined by potential exporters.

2.4 Pre-shipment handling

For fruits and vegetables, this can include application of appropriate post-harvest treatments (eg fungicides), short pre-shipment storage times, and avoidance of mechanical damage such as bruising from either sorting or grading machinery or from rough handling of cartons.

For frozen goods, the principal requirement is maintenance of temperature throughout all links in the transport chain, without excessive periods lacking refrigeration.

2.5 Packaging

Packaging has to protect produce, so must have adequate strength, if necessary when damp, for the anticipated use. It may also need to incorporate wraps or liners to minimise loss of moisture. However, it must also in the case of respiring produce provide sufficient ventilation to allow heat and respiration products to be removed. Packaging materials must not contain substances likely to produce taints or odours. Cartons must be of a suitable size and shape to protect the product from movement and also from external pressure. For palletised transport, cartons must be adequately secured to pallets without jeopardising any air movement designed into the cartons.

Successful packaging systems have been developed over the years, and these are frequently more sophisticated in their requirements than is immediately obvious. Changes to such systems should be considered with care.

2.6 Pre-cooling

For some fruits, such as citrus and banana in marine transport, it is normal practice to load them warm, and cool them during transportation. These are exceptions; generally it is essential to cool fruits to their transport temperature as soon as possible after harvest. For this purpose air cooling tunnels, hydrocoolers, or vacuum coolers may be used, all of which can extract heat far more rapidly than is possible during transportation.

In all transport equipment, cooling rates will be relatively slow, and very dependent on position within the stow. Whilst cooling tunnels may achieve 7/8 cooling times of only a few hours, in transport it is more usual to achieve times of 2 to 6 days.

If the cooling demands on the transport equipment are increased excessively due to inadequate precooling, there will be uneven cooling through the cargo, and some areas will be delivered with reduced residual storage life. This loss is due to the loading condition and no amount of care in transport can overcome it. For produce with a high metabolic rate, if it is not yet adequately precooled, the respiratory heat can be so high that correct storage temperatures in transport are unachievable.

2.7 Air circulation

For frozen goods, air circulation is necessary to remove heat entering from the outside of the storage space through insulated walls. For respiring fresh produce, it is also necessary to remove respiratory heat. For some produce, cooling is also necessary.

Transport equipment is designed to provide adequate air circulation in properly packaged and properly stowed cargoes. Wrong packaging or careless stowage can negate this, and can give overall or localised inadequacies of air movement.

Air circulation is also important in retail display – open multi-deck cabinets depend on proper air circulation to provide reasonably uniform product temperatures.

2.8 Temperature control

Temperature control for frozen goods is less critical than that for chilled goods. The former require a maximum temperature (e.g. -18°C) not to be exceeded, whereas chilled goods on long journeys often require temperatures maintained within a band of 2°C or less. In retail display, chilled goods are normally expected to be kept within a 5°C band or less.

The controllability of transport equipment designed for use with chilled cargoes is of necessity good. However, if equipment primarily designed for frozen goods is used for chilled transport, it may be possible to obtain wider temperature swings or lower temperatures than are desirable. Wide swings mean an appreciable time at higher-than-planned temperatures, with consequent loss of storage life. Low temperatures may mean freezing or damage from chilling injury.

2.9 Air freshening

Air freshening during transport is necessary for cargoes of respiring produce to take away carbon dioxide and ethylene before they reach excessive levels. Air freshening, or fresh air ventilation, requirements are usually clearly specified by shippers, and these requirements should be adhered to.

2.10 Cross-contamination from other cargo

Cross-contamination can be of two types. The most obvious is the transfer of taint or odours from one cargo to another. The other is the transfer of ethylene from produce with high ethylene production rates to ethylene sensitive goods, leading to premature ripening. Carriers usually have clear instructions to prevent inappropriate mixing of cargoes, but care may be necessary to ensure that these instructions are also available to transhipment terminals inland or at ports.

2.11 Insect infestation

Where problems of insect infestation are likely, procedures will have been established by importing countries which may require fumigation or cold treatment of particular produce from some growing

areas. It is essential that would-be exporters are aware of requirements of importing countries in this respect.

2.12 Journey time
Marine transport is generally very reliable, but by the nature of things, breakdowns and storms can sometimes create delays. So also can industrial action, often beyond the control of the carrier. Where such things lead to appreciable delays, damage to more perishable produce can occur.

2.13 Time without refrigeration
Goods can be without refrigeration for short periods during land journeys to and from ships, and can occasionally be without refrigeration due to mechanical breakdown of equipment. Breaks in refrigeration of a few hours may be acceptable for many, but not all, produce types. Breaks of a few days are likely to pose problems for all types of produce.

2.14 Retail sale
Following transportation, the cold chain continues through the wholesale handler and the retail store to the customer. In the store, proper equipment sensibly sited and properly used is necessary. Losses at this stage waste all the effort and energy which has been expended earlier in the chain.

3. WHAT CAN GO WRONG?

Any one of the items listed in section 2 above could go wrong and lead to a disastrous result. Whilst remembering that mostly things don't go wrong, we can consider each heading in turn and identify potential weaknesses in today's cold chains.

3.1 Produce temperatures
It is important for the shipper of perishable produce to know the storage characteristics of the produce, and the most appropriate temperature regime. This will vary depending not only on produce type, but also on variety, growing area, and sometimes the nature of the growing season (early/late, wet/dry). If the appropriate temperature is not known, it should be determined by small-scale storage trials, not by large-scale experimental shipments. Failure to do this has led to several expensive failures known to the author.

In some cases the preferred temperature is still a matter for debate. As an example, there seem to be several different ideas as to how best to transport garlic. Garlic may be carried at a preferred temperature between -4°C and 0°C, or at ambient temperature with good ventilation. In such cases, shippers' instructions have to be clear and have to be followed.

There are still occasions on which confusion between Fahrenheit and Centigrade temperatures leads to errors. 0°F is very close to -18°C, and these are popular temperatures for carriage of chilled and frozen goods respectively, so confusion between 0°F and 0°C can easily go un-noticed. It would be good if all could use accepted international units, but the USA seems averse to this idea.

For some cargoes, temperatures are prescribed by the country receiving the goods. Quick-frozen foodstuffs for Europe must be carried at -18°C or below from point of production. Fresh fruits under plant quarantine regimes must meet tightly laid down temperature and time limitations. Some countries may not accept frozen goods which have been off refrigeration for more than a specified time, regardless of temperatures achieved. In all these cases, failure to meet requirements is a total commercial failure unless the goods can be diverted to a different destination where they will be acceptable.

In transport, there are often pressures to carry frozen goods at ever-lower temperatures. For fish and ice cream, this offers quality benefits, but for other goods it is an unnecessary waste of energy and should be avoided if possible. It may be a way of trying to overcome known deficiencies further along the cold chain such as long times without refrigeration or inadequate frozen store capacity – this is not the right solution to these problems.

3.2 Transport equipment

The shipper may try to reduce costs by avoiding temperature control on less critical journeys. This can be unwise. Guidelines have been published previously (Heap and Pryor, 1993, also ICCT, 2000). These recommend as follows:

- For any goods requiring close temperature control, refrigeration is essential. If temperatures need to be maintained within a band of 2°C or less, refrigeration should be virtually continuous.
- At the other extreme, for less sensitive goods with a maximum temperature tolerance of 30 degrees C or above, refrigeration is only necessary for storage on land at high ambient temperatures. For containerised shipments at sea, a protected stow may be requested.
- If the maximum permitted temperature is 25°C or lower, refrigeration should be used for any journeys through the tropics and for any journeys anywhere in summer.
- If cargo requirements are marginal, either in terms of temperature tolerance or in terns of possible delays at high ambient temperatures, then the only safe option is to use refrigeration. Frozen foods may sometimes be carried without refrigeration for short journeys as long as the cargo does not rise above the specified maximum temperature. This should only be done with the consent of the owner of the goods.

When transporting by air, there is very little availability of even limited temperature control. For a Dublin to Auckland journey via Copenhagen and Singapore taking a total of 96 hours, only 40 hours are in the air. In the aircraft, temperatures might range from 2°C to 18°C, and on the ground the range might be from -2°C to 30°C. The results of a "controlled temperature" air shipment from Europe to USA are shown in Figure 1. In this case, temperatures varied from -1°C to 26°C despite the instruction to keep between 2°C and 8°C. Most of the time the terms "cold chain" and "air freight" seem to be incompatible; the journey time is mostly not in the aircraft.

In developed countries there is an increasing demand for home delivery from supermarkets, especially from Internet sales. There is generally a lack of suitable vehicles and operating procedures for delivery of frozen or chilled goods, resulting in home deliveries at temperatures above regulatory limits. Admittedly the temperature control is better than that in the family car which would otherwise carry the goods, but that does not detract from the supermarket responsibility to maintain temperature to the point of delivery.

In developing countries, there will often be a lack of suitable equipment to provide a proper cold chain. This is a need which leads to the loss of a large quantity of foodstuffs. It has been estimated that 300 million tonnes of produce are lost annually through non-use of refrigeration, mainly in developing countries (IIR and UNEP, 2002).

For all forms of transport refrigeration, inadequate maintenance of equipment can lead to problems.

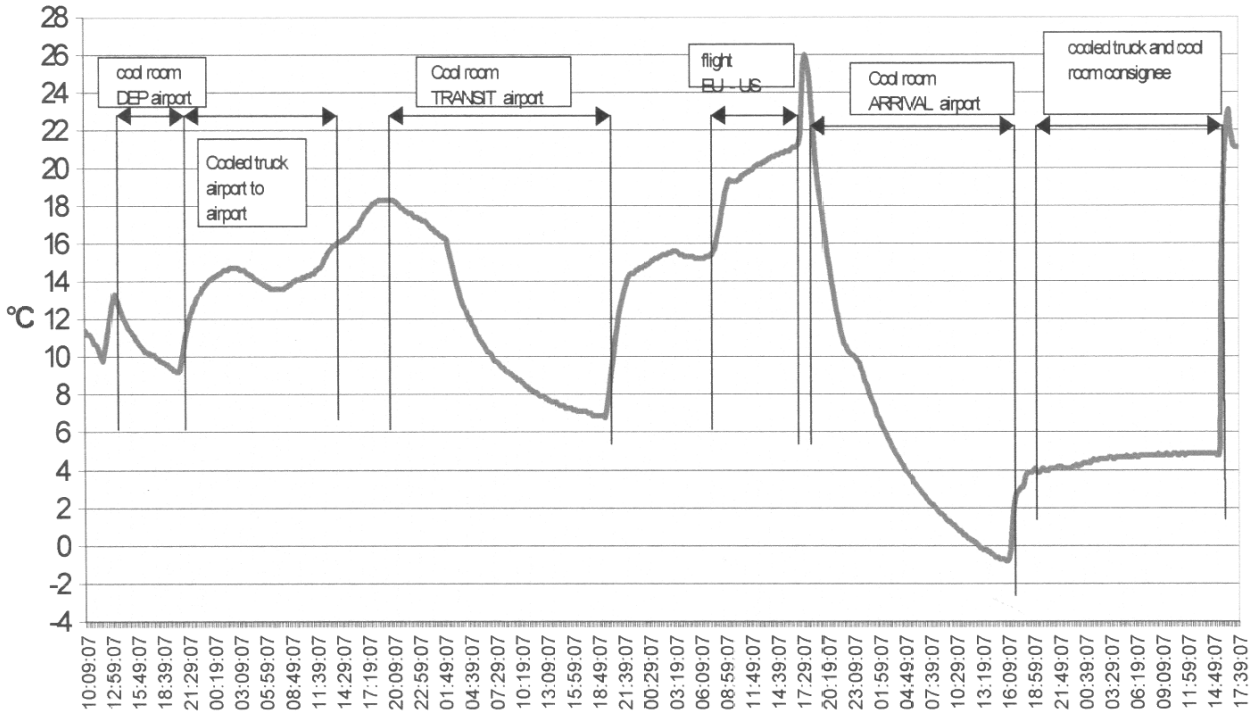

Figure 1. Temperatures in an air freight shipment with the instruction to maintain temperatures between 2°C and 8°C.

3.3 Produce quality

Nowadays, the export of inferior quality produce is rare. There are dangers, however. Countries used to exporting by air may find that increasing market size or increasing costs suggest a move to sea freight. The quality standards generally used for air freighted produce assume a total life of at most a few days, and are lesser standards than may be needed for the slower sea freight journey. Handling and pre-cooling requirements will also differ substantially. This means that goods known to be suitable for export by air may well fail if sent by a slower form of transport.

3.4 Pre-shipment handling

The dangers of bad mechanical handling, poor temperature control, and inappropriate chemical treatments are self-evident. In established cold chains these should present no problems, but they must be considered for new chains being set up.

Perhaps the commonest problem is perishable chilled produce which is too old at shipment. It can still look good, but may not have the storage life to survive the journey and subsequent shelf life requirements. This problem can occur with whole shipments, or sometimes with only part of a load which has been loaded into a hold or container over a period of several days. Very often such loads result in claims, which can be difficult to resolve if there are inadequate records of pre-shipment temperature history.

3.5 Packaging

Usually, packaging is well designed for its function. Problems occur if packaging systems are changed without regard for transport requirements, or if packaging materials are incorrectly stored and become damp. Such problems are more likely in general cargo than in temperature-controlled shipments. However, note the next section.

3.6 Pre-cooling

The requirements for pre-cooling have been stated above. It is not always appreciated that even two degrees of inadequate precooling of a chilled cargo can mean that the warmest part of the cargo will be above the required temperature for up to two weeks. This is not because of any deficiency in the equipment, but due to the limited heat transfer available with small temperature differences and relatively low airflow rates.

Pre-cooling often uses horizontal airflow; the flow in transport equipment is vertical. If ventilated packaging is designed for the airflow in pre-coolers, there may be little ventilation for vertical flow. This means that any warming up in transit makes it very difficult to recover temperature.

A twelve-month study at a cut flower consolidation dock (Staby and Reid, 2005) showed that on average, none of 57 growers delivered at the right temperature: 46 growers were more than 3°C too warm and of these, 9 were over 8°C too warm. This is probably typical of many shipments of chilled goods. The same authors show the effects of subsequent poor temperature control on vase life in what they regard as typical conditions for flower transport (Figure 2).

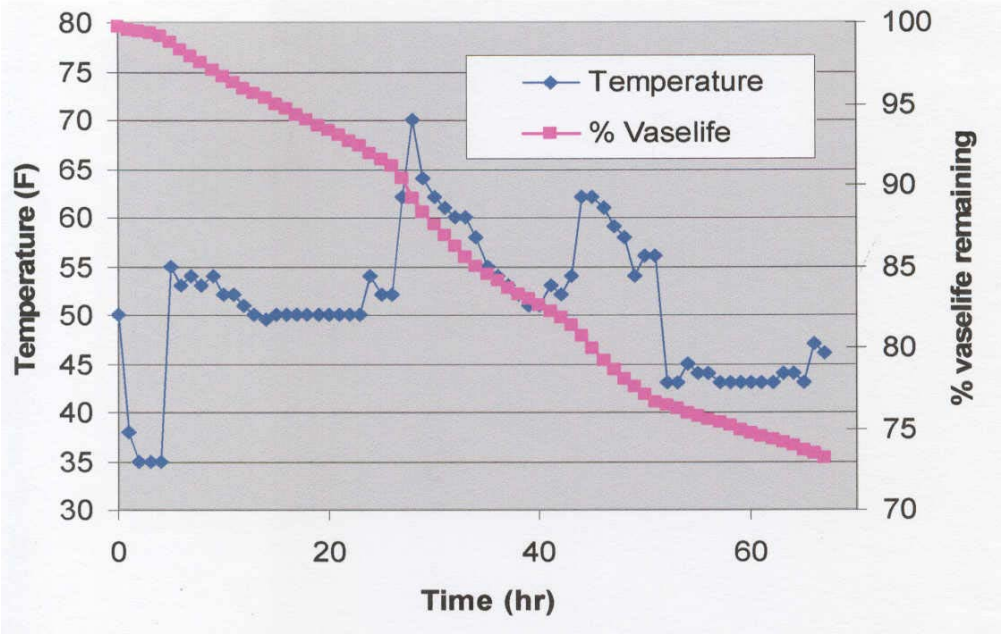

Figure 2. Effect of poor temperature control on vase life of flowers (Staby and Reid, 2005).

3.7 Air circulation

Failures of air circulation can occur due to bad stowage. Defrost system failures can lead to icing of the coil and airflow restriction. Also, very occasionally, blocked container drains can lead to ice build up which restricts airflow. The consequence of such events is at best wider range of cargo temperature, at worst a loss of temperature control.

3.8 Temperature control

Apart from the problems mentioned above, it is possible to have a failure of a temperature control sensor in a refrigeration system. The effects of this depend on the particular control system – frequently nowadays control will be taken over by another sensor with a suitable temperature offset.

3.9 Air freshening

Fresh fruits and vegetables are living organisms and require fresh air to allow respiration. Without ventilation during transport, respiratory gases can build up and damage the produce. Historically,

high ventilation rates have been used, which impact unfavourably on temperature control, humidity, and energy use. Calculation programs are now available which allow easy calculation of ventilation requirements in containerised transport for given upper levels of carbon dioxide or ethylene.

These programs have been described elsewhere (Heap and Marshall, 2003) and were used to compare necessary ventilation rates with those generally used in transport. It was shown that, for produce with low rates of respiration, ventilation rates are generally appreciably higher than necessary.

Problems can be compounded by inaccurate or vague calibration of air freshening vents, or by ventilation rates specified in cfm, m^3/h, or ach (air changes per hour) with different units labelled on the equipment; m^3/h are preferred.

In banana transport, it is common to cool the fruit in transit, and whilst this is happening ventilation is restricted. Carriage instructions to reflect this can be contradictory, sometimes requiring the impossible combination of maximum cooling and high ventilation. Clear instructions should be agreed between shipper and carrier. For bananas once cooled, ventilation is needed to remove ethylene; as ethylene is not normally measurable on board ship, the ventilation requirement is often specified by reference to a maximum carbon dioxide level much lower than the levels of this gas acceptable to the fruit. This is usually not understood and can lead to confusion.

3.10 Cross-contamination from other cargo

Ethylene cross-contamination (real or alleged) of fruit cargoes is a common source of claims for damage. It may be difficult to distinguish between this effect and the effects of less-than-perfect post-harvest handling.

Tainting of cargoes, by inappropriate packaging, dirty cargo spaces, or leaking chemicals, occurs occasionally. These events are rare but can be very expensive.

3.11 Insect infestation

Problems of insect infestation are generally rare in refrigerated cargoes, though failure to meet low temperature quarantine requirements can delay outturns and impact on fruit quality.

3.12 Journey time

Journey times by sea are generally very predictable; bad weather can cause small delays, industrial action or major breakdowns can cause very long delays. Road journeys can be held up by traffic, or by customs delays at national borders. Airfreight can be (and often is) delayed due to unavailability of space on flights – passengers and more valuable goods take priority.

3.13 Time without refrigeration

Effects of time without refrigeration can be predicted by computer programs (not by rough rules of thumb). This is most likely to be an issue at busy export terminals or trans-shipment ports, which do not always have sufficient power supplies for the equipment in their care.
For some countries there may be regulations precluding the import of frozen goods which have been off refrigeration for more than a specified time, regardless of the prevailing conditions. This can lead to cargo rejection, so carriers need to be aware of such rules.

3.14 Retail sale

Problems of temperature control in retail premises have been identified over many years. Deliveries to stores may be at the wrong temperature, and deciding how to handle this can be difficult, especially if there is a shop demand for the goods. Ideally there should be temperature records and a

decision could be made dependent on time and temperature tolerances. In practice, perfectly sound goods may be rejected as too warm, and the same goods redelivered later at a lower temperature may be accepted.

Retail display cabinets can be a weak link in the cold chain. Cabinets should be of good quality (e.g. to EN 441), loaded at the correct temperature, any air inlets and load lines respected, and should be sited away from very warm areas. Open multi-deck cabinets are the most difficult, and there have been many studies of possible design improvements, including the possible use of heat pipes along shelves to provide more uniform temperatures (Wang et al, 2005).

3.15 General issues

Throughout cold chain transportation, the longer the journey time the more carefully temperature has to be controlled. Whilst this is well understood, unfortunately the converse is also taken as acceptable, that is, the shorter the time, the less care is needed. This usually results in the weakest links in the chain being the shortest ones; these include transit ports, airfreight, and retail display. It is important to ensure that those responsible for these areas understand their part in the total chain, and accept their responsibility not to spoil the efforts of others to get goods to the market in the best possible condition.

The increasing use of HACCP techniques, in transit temperature monitoring using portable recorders, and whole chain monitoring using RFID systems, together with ever-tighter food safety legislation, will highlight increasingly where the real problems lie. They will also ensure that responsibility for product losses results in financial loss to those truly responsible, which is not always the case at present.

4. ENVIRONMENTAL ISSUES

Transport is responsible for a large proportion of the global emissions of climate change gases. This has led to concerns about the long distance transport of foodstuffs which maybe could be sourced more locally, and the terminology “food miles” (sadly not “food kilometres”) has appeared. The implication is that “food miles” are bad, and should be minimised. Is this a serious issue for the future?

A recent UK report (AEA Technology, 2005) gives estimates of the distribution of CO_2 emissions for food transport to and in the UK. Details are in Table 2. This shows clearly that the environmental issue is more about local distribution systems than about long distance transport – perhaps a surprising finding. In terms of emissions per tonne-km, the private car is the worst, air-freight little better, and sea freight by far the best.

There is also the environmental issue regarding the use of HFC refrigerants, which are almost universal in transport refrigeration. This sector is a very small part of the total refrigeration and air conditioning industry, but is less amenable to the use of some alternatives because of safety considerations for flammable substances in tunnels, ferries and ships’ holds. This issue will be a major future concern for equipment manufacturers.

Transport mode	CO_2 emissions as a proportion of total food transport emissions (%)	Transportation (tonne-km) as a proportion of total transportation (%)
UK road, commercial vehicles	38	21.2
Overseas road transport	14	7.4
UK road, private cars	13	0.1
International by road	12	5.5
International by sea	12	65.2
International air freight	11	0.5

Table 2. Transport emissions, food to UK.

5. SOLUTIONS FOR THE FUTURE

Continuing problem areas may be categorised into four groups; produce related, equipment related, stowage and handling, logistics.

5.1. Produce related issues

There are too many occasions when the correct optimal conditions for the cargo are either not known or not correctly and completely specified. This is especially the case for fresh fruit and vegetable cargoes. The reason may be that the knowledge does not exist for the particular produce/variety/growing area, in which case practical research is needed. If the knowledge does exist, the shortfall is in the proper training of those responsible for shipping the cargo.

The shipping of poor quality produce will always lead to problems, and can only be prevented by educating shippers. However, to some extent market forces will provide this education.

There would be benefits from further research into the choice of optimal air freshening rates in order to minimise energy use whilst protecting cargo.

5.2. Equipment related issues

The problems here are of appropriate choice of equipment and transport mode for the particular journey, and proper maintenance of equipment. These problems should be minimised as long as experienced carriers are used, but there is a need for continuing education of both shippers and carriers. It is important that cold chain systems include provision for proper pre-shipment checking of refrigeration systems and insulated enclosures.

In developing countries, the biggest problem is often the non-availability of suitable equipment at the right place and time. Investment in appropriate equipment and systems is needed, together with education in the use of these.

Perhaps the area with greatest scope for equipment improvement is the retail display cabinet, with its conflicting requirements of good temperature control and good customer access. Otherwise there is no great need for research into other types of equipment over and above that carried out by major manufacturers – there is plenty of evidence that the technology exists for any foreseeable demands the customers are willing to pay for. Persuading customers to spend more initially to save energy and running costs in the long term is not easy. The technology is already ahead of the market.

5.3. Stowage and handling

There are examples of poor handling (especially of shipment of perishable produce that is not fresh), poor stowage, inadequate packaging, lack of proper pre-cooling, and occasional tainting of cargo. All of these can be minimised if those responsible are well trained and if systems are in place to ensure that only those who know what they are doing take the relevant decisions.

5.4. Logistics

The main logistics issues are ensuring that expected journey times are consistent with product life and minimising time off refrigeration. Problems are most likely to occur at export terminals and transit points, both for sea freight and air freight. For road transport, traffic congestion and customs delays need to be considered. Proper planning and operating systems overcome these difficulties to some extent, but there is always some degree of uncertainty remaining. Some margin for delays should be built in to the planning process. For the cold chain, it is always a journey which has to be achieved, not just a destination.

5.5. The main solutions

It is seen above that the main requirements are for education and training, and for provision of good operating systems. Many of today's problems can be overcome if people understand their place in the overall cold chain, and understand the needs of the product. The training courses and educational literature provided by the IIR and others need to be more widely used.
The provision of standardised procedures, possibly in association with the new standard ISO 22000, will help overcome many potential problems, but these are no substitute for proper understanding based on education and training.

There is always a need to see if we can do better, and the IIR (2005) has produced a list of research priorities for Commissions D1 and D2, which indicates areas where progress might be made. Those interested in research in these areas should consult this list.

The way to success has been well summarised by Hartley (2005) as follows:

- Know your products and routes
- Educate your team on modes of transport
- Select the best mode using risk analysis
- Use the best provider you can find
- Use quality control to manage both planned and unplanned changes.

It is difficult to find better advice than this.

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