

# The standardised freight container: vector of vectors and vector-borne diseases

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## Summary

The standardised freight container was one of the most important innovations of the 20th Century. Containerised cargoes travel from their point of origin to their destination by ship, road and rail as part of a single journey, without unpacking. This simple concept is the key element in cheap, rapid transport by land and sea, and has led to a phenomenal growth in global trade. Likewise, containerised air cargo has led to a remarkable increase in the inter-continental transportation of goods, particularly perishable items such as flowers, fresh vegetables and live animals. In both cases, containerisation offers great advantages in speed and security, but reduces the opportunity to inspect cargoes in transit. An inevitable consequence is the globalisation of undesirable species of animals, plants and pathogens. Moreover, cheap passenger flights offer worldwide travel for viral and parasitic pathogens in infected humans. The continued emergence of exotic pests, vectors and pathogens throughout the world is an unavoidable consequence of these advances in transportation technology.

## Keywords

*Aedes albopictus* – Airfreight – Cargo – Chikungunya – Containers – Freight container – Globalisation – Shipping – Transport.

## Introduction

The freight container (also known as the ‘intermodal container’) was one of the most important innovations of the 20th Century. Indeed, globalisation implies containerisation, for this single device has been key to the advent of cheap, rapid transport of more than 90% of all non-bulk cargo. (Bulk cargoes are materials that are transported without packaging, e.g. oil, gas, mineral ores, chemicals and grains.)

The container revolution began in the 1950s. Until then, delivering items from factory to destination could involve at least six transfers:

- from factory to road (and/or rail) vehicle
- from vehicle to dockside holding shed
- from holding shed to ship
- from ship to holding shed at the port of destination

- from holding shed to vehicle
- from vehicle to final destination.

For most goods, every stage involved the manual handling of individual items. For example, at the dockside, teams of dockers and deck-hands worked in the holds of cargo ships to load items, piece by piece, onto wooden pallets. These were then hooked to a cable, hoisted by crane to the dockside, and transferred on the pallet to a holding shed to await transport. Not surprisingly, loss by pilferage was a major problem.

By contrast, goods in freight containers move from source to destination by ship, road and rail as part of a single journey, without unpacking. This offers great advantages in labour, speed and security. Dimensions are standardised to 10-foot (3.05 m), 20-foot (6.10 m) and 40-foot (12.19 m) lengths. (The cargo capacity of container ships and terminals is usually expressed as ‘twenty-foot equivalents’.) This simple concept has made transport incredibly cheap.

For example, with oil at US\$75 a barrel, it costs about US\$6,000 (€4,500) to ship a 40-foot (12.19 m) container from Shanghai to San Francisco.

The key element in containerisation – standardisation at the international level – took about 20 years to achieve. Today, each of the 20 million freight containers that circulate around the world has its own unique reporting mark, so its whereabouts are readily traceable in a computerised system that is shared by the exporter, the shipper, the importer and the customs and excise authorities.

At sea, modern freight containers are stacked in multiple layers on purpose-built ships; some can carry more than 14,500 units. Before containerisation, multiple cranes were a part of the silhouette of cargo ships, but most container ships have no shipboard cranes at all. Instead, specialised on-shore container cranes are mounted on a framework that can range along the quay to be positioned alongside the docked ship. These container cranes can pick up and transfer containers to a waiting lorry or railway wagon in less than 2 min. To give an idea of what this means: there are four container terminals in Singapore, with berths for 37 ships, and these handle nearly 21 million containers per year.

In pre-container days, as already mentioned, breakages and pilferage were major problems; up to 25% of goods could ‘fall off a lorry’ on the journey from the shipper to the receiver. Today, the containers are locked and sealed and their contents are not visible from the outside. Thus, they can be shipped from their origin to destinations on the far side of the world without ever being opened. The drawback to this is that inspection of their contents is highly impractical.

## Case study: the global dispersal of *Aedes albopictus*, the Asian Tiger mosquito

In June 1983, a single adult specimen of *Aedes* (*Stegomyia*) *albopictus* (Skuse), a mosquito native to Asia, was captured during studies of mosquito-borne viruses in Memphis, Tennessee. The species had been recorded as far west as Hawaii, but never in the western hemisphere. It is a vector of dengue and chikungunya viruses in urban areas, albeit considered less effective than *A. aegypti* (8). Speculation on how it had arrived in the continental United States drew attention to containerisation, and it was suggested that this relatively new technology would lead to further introductions of medically important insects (6).

In 1985, *A. albopictus* was detected in Harris County, Texas, which includes the city of Houston. Surveillance by the local authorities revealed that it was widespread and common throughout the area, and had become a major nuisance. Discarded used tyres – abundant in many areas – were infested, and its distribution indicated that *A. albopictus* could have been present for several years before detection. Early in 1986, during investigations of the infestation, a chance encounter in the field revealed that, since the late 1960s, there had been an extensive and rapidly growing national and international trade in used tyres. Millions were being imported annually from all over the world to destinations throughout the United States (7). It appeared likely that the new species had been imported in such tyres, perhaps from Japan, the largest exporter. Further investigation revealed that the used tyre trade was not restricted to Japan and the United States; virtually every country in the world imports and/or exports used tyres. Without containerisation, this trade would have been unworkable because tyres are too awkward to handle on pallets.

Tyres are shipped between countries for many reasons, but mostly for retreading, either for local use or for return to the country of dispatch. Although all the major tyre companies manufacture their tyres for multiple lives – i.e. they are designed to be retreaded – the practice is less common in some countries, such as Japan, so these are the principal exporters. About half the truck and bus tyres on the road in the European Union (EU) are retreads. The proportion for passenger cars is much lower, except for winter tyres; up to 20% of these are retreads in some countries. International specifications for aircraft tyres allow retreading up to 12 times, and more than 90% of all aircraft tyres are retreads, as are the giant tyres on heavy vehicles such as earthmoving and agricultural equipment. The apparatus for retreading car and truck tyres is relatively simple, but others may have to be shipped for long distances to special facilities.

In the summer of 1986, a survey of 12 states – Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Louisiana, Mississippi, Missouri, Ohio, Tennessee and Texas – revealed that *A. albopictus* was present in 48 out of 57 counties surveyed (84%). An alert from the Pan American Health Organization prompted national authorities in Brazil to examine specimens of an *Aedes* species that had been awaiting identification. These also proved to be *A. albopictus* and, by the end of July 1985, infestations had been detected in 63 municipalities in three Brazilian states. Meanwhile, an exhaustive inspection of 22,000 used tyres arriving in Seattle from Japan revealed that 25% contained water (2) and five species of mosquitoes were identified, including *A. albopictus* and three other exotics.

A study of resistance to cold and the duration of photoperiod required for the onset of winter diapause in

*A. albopictus* gave further evidence that the infestations in the United States had originated in northern Asia, perhaps South Korea or Japan (4). Interestingly, Houston was at the minimum latitude for infestations at that time. Florida was unaffected, perhaps, in part, because the maximum day length was too short to terminate winter diapause.

By late 1986, it was apparent that the species was widely established in the United States and Brazil. Moreover, it seemed likely that it had been present in both countries for a number of years prior to detection. It was also apparent that domestic interstate traffic in used tyres was a major factor in the continued dispersal of the insect within both countries. Despite its widespread presence and abundance, there was considerable pressure on the United States government to prevent further introductions, mainly on the grounds that this would limit the genetic variation of the newly established population, as well as prevent the introduction of exotic viruses. A federal regulation was implemented by which all used tyres arriving in the United States from Japan, Korea, Chinese Taipei, the People's Republic of China, Hong Kong, Thailand and other Asian countries where *A. albopictus* was known to occur should be certified as dry, clean, and free from insects. All non-compliant cargoes were to be fumigated with (highly toxic) methyl bromide, or treated with a pressurised spray of detergent/water solution at 88°C, or by steam cleaning.

Inspections and treatments were highly labour intensive, yet the maximum penalty for non-compliance was US\$1,000. This was hardly a deterrent, especially as staff from the Division of Quarantine of the Centers for Disease Control could only make cursory examination of, at best, ten percent of all cargoes arriving at a few selected seaports. After several years it was apparent that the effort was merely cosmetic, and the regulations were quietly withdrawn.

The experience of the United States government with used tyre imports underlines four problems that are, in most cases, insurmountable:

- under international law, cargoes are almost invariably the responsibility of the importer, not the exporter
- cargoes are no longer handled item by item so, if inspection is to be effective, the entire freight container must be unloaded
- speed of transit is a crucial element in containerised transportation, not only for the shipper, but also to prevent congestion at the port
- freight containers are often packed tightly to the roof, so fumigation is of doubtful efficacy unless the contents are unloaded.

In summary, although it is not difficult to survey a species once it has been detected, it is much more difficult to

intercept new introductions when they occur. Indeed, it is unrealistic to expect authorities to establish routine surveillance for imported species that have not been detected in the past, particularly when potential infestation sites may be anywhere on a whole continent.

## Europe

No attempt has been made to restrict the importation of used tyres into Europe. Moreover, after the initial detection of the species in Memphis, Tennessee, it was learned that *A. albopictus* had been present in Albania for at least ten years and was a major nuisance in many areas (1). At that time, the country was politically and commercially isolated, with little or no contact with the outside world, except China.

The first infestation of *A. albopictus* in Europe, apart from Albania, was detected in Veneto, northern Italy, in 1992, and traced to imports of used tyres from Atlanta, Georgia (3). Since then, *A. albopictus* has been detected in 16 countries at least once and is considered present and expanding its range in:

- Albania
- Croatia
- France
- Greece
- Monaco
- Montenegro
- Italy
- San Marino
- Slovenia
- Spain
- Switzerland
- Vatican City.

Italy is by far the most widely infested country and in many places infestation rates are remarkably high. In some parts of Rome, including important tourist sites, biting rates are a major problem for at least five months of the year.

Import data for used tyres indicate that multiple introductions are likely to have occurred (and probably continue to do so), but the progressive advance of the species into southern France and Switzerland suggests dispersal at the local level. Interestingly, a second mode of importation was identified in the Netherlands: workers were plagued by *A. albopictus* when they opened shipping containers filled with 'Lucky Bamboo' plants imported from southern China (*Dracaena sanderiana*, a species of lily from the Cameroonian rain forest, is widely marketed as a decorative plant). More than a million of these plants are imported every year, each in a small tube of water. The mosquito became a considerable nuisance in glasshouses

(10), but has not become established outdoors, perhaps because the South China strain does not have a winter diapause mechanism.

As in the United States, the strains now established in Europe are adapted to survive northern winters. If winter temperatures define the limits of their distribution, there is no reason to believe that infestations will not move northwards, perhaps as far as Scandinavia. The average minimum temperatures in January in Beijing, the People's Republic of China ( $-10^{\circ}\text{C}$ ), and Seoul, South Korea ( $-6^{\circ}\text{C}$ ), which are both within the original range of distribution of *A. albopictus*, are on a par with Stockholm, Sweden ( $-3^{\circ}\text{C}$ ). In Albania, the species is present in mountain areas where there is snow cover for two to three months of the year (E. Velo, personal communication).

Beyond Europe, the species is established in the Bekaa Valley, on the Lebanon/Syria border (anonymous source to the author). Here again, it is not unlikely that it will eventually move eastwards into central Asia. Finally, *A. albopictus* is common in urban areas and in rubber plantations in Cameroon, Equatorial Guinea, Gabon and southeast Nigeria. It has been implicated in an outbreak of chikungunya in Gabon (5) and there is reason to believe it may become a significant vector of yellow fever.

In summary, in the space of a few decades, an alien species has exploited a modern chain of transport that has brought it from Asia to the Americas, Europe and Africa.

## Airfreight containers

Containerisation has also been a key factor in the enormous increase in air cargo services and trade in live animals and perishable agricultural products. For example, 450,000 tons of vegetables, fruit and flowers are exported annually from Kenya to the EU, to the value of about one billion Euros. The growth of this trade has been spectacular: it was non-existent 20 years ago. Exports from other African countries – Morocco, Senegal, Mali, Burkina Faso, Cameroon, Ethiopia, Madagascar and South Africa – are also booming. Indeed, nearly all countries in the tropics and sub-tropics export perishable agricultural products by airfreight to the United States, Canada and Europe. Ecuador and Colombia, for example, are major competitors with Kenya in the European market for fresh-cut roses, even during seasons when locally grown flowers are available.

In air transport, space is money and weight is at a premium. Airfreight containers are made of aluminium or aluminium and plastic, and, depending on the nature of

the goods to be transported, may have built-in refrigeration units. Dimensions are more complex than for surface transport, because these containers are contoured to fit the plane. In many cases, this contouring is simply a triangle removed from one or two corners of the profile, leaving a significant gap between the container and the fuselage along the length of the cargo hold. In others, the contour is curved to fit a specific model of aircraft so as to completely maximise cargo volume. In passenger aircraft, freight is shipped in the lower half of the fuselage, under the floor of the cabin; in cargo aircraft, containers are designed to fill both halves.

The technology and handling of airfreight is complex, tailored to suit the nature of the cargo, and may vary between companies. Cut flowers, for example, are often wrapped at source and carefully arranged in polystyrene boxes. Transportation to the airport may be in large, air-conditioned containers. In some cases, however, a stream of cold air is passed through the boxes before they are transferred to the airport. Forced-air cooling, or cooling by dry ice or by other means, may be repeated at the airport until the boxes are packed into airfreight containers and transferred to the aircraft. Fruit, such as mangoes, is arranged in trays, with a space between each tray, and stacked on aluminium pallets. Green beans are often shipped pre-cut and pre-packed, ready for the supermarket shelf.

The opportunity for arthropods to stow away in cargo or in cargo holds can occur at the source or during the loading of containers. With such large-scale commerce in perishable goods, packing is usually done in large air-conditioned buildings, where populations of flying insects may be low. However, outdoors, at night, bright lights and the presence of ground personnel may attract blood-feeding insects to the hold. In addition, cage tests have shown that mosquitoes and other insects can survive long-distance flights (e.g. from Melbourne to Singapore) in the wheel bays of aircraft, where in-flight temperatures ranged from  $8^{\circ}\text{C}$  to  $25^{\circ}\text{C}$  despite outside temperatures of less than  $-50^{\circ}\text{C}$  (9).

A search for specific information on the treatment of air-cargo holds is frustrating because, although some countries have strict requirements to prevent the importation of exotic arthropods, the methods used are imprecisely defined. In part, this is because treatments vary according to the rules drawn up by the country of destination, as well as to the nature of the cargo, the material used in packing and the materials used in the air-frame structure. In some cases, fumigation is used; in others, residual treatments are applied, but in many cases there is no treatment at all. Regulations for the disinsection of, say, flowers, may mean that cargo areas have to be decontaminated before loading a subsequent cargo of vegetables and other foodstuffs.

## Livestock

Containerised airfreight has also given unprecedented mobility to livestock. Racehorses travel between racetracks like business executives to meetings. Specially designed horse boxes allow for constant care by professional in-flight grooms. The cargo holds of passenger aircraft can handle up to four horses; specially designed cargo jets can handle up to 80. Hundreds of thousands of day-old chicks travel between countries as far apart as China and Nigeria. Millions of cage-birds are shipped between continents (five million cage-birds are imported by the United States each year). Wild animals are exchanged between zoos, and domestic 'jet-set pets' travel in the cargo hold while their owners are in the passenger cabin above. Here again, treatment of the containers and of the interior of the cargo hold varies greatly, according to the regulations of the destination country.

Lastly, even in countries where there are strict regulations for imported cargoes, such directives rarely exist for shipments within those countries. For example, there is no disinsection of freight containers or aircraft within the EU or the United States, yet many cargoes travel long distances within those regions. (This also applies to used tyres. A search on *Google* yields 130,000 hits for used tyre companies in Europe. Most of these refer to dealers, not importers, so distribution after arrival in a country is a further means of dissemination.)

## Passenger aircraft

Cases of 'airport malaria' – infections acquired in or near international airports – are well documented. It is probable that many of these are caused by insects emerging from the cargo holds, but surveys at international airports have frequently revealed live insects, particularly mosquitoes, in the passenger cabins. The World Health Organization stipulates in-flight treatment with a short-acting aerosolised insecticide or treatment of the interior surfaces of the aircraft with a residual formulation. Some countries have adopted a third method in which aircraft are sprayed by aerosol before passengers embark. In truth, only 16 countries require any treatment at all and, of these, few receive flights that originate in countries where diseases such as malaria, dengue fever and chikungunya are endemic. Moreover, although in-flight sprays may be effective in the cabin, they are not applied in the overhead bins, where insects can be well hidden among baggage and clothing.

The theme of this article would not be complete without mentioning the transport of pathogens in infected humans, for this is now a major global problem; the

International Air Transport Association predicts 980,000,000 international passenger flights by 2011. As an example, molecular sequencing has repeatedly demonstrated the exchange of dengue viruses between Asia and Latin America, and among Pacific and Caribbean islands. Another example, a particularly interesting incident, was a small epidemic of chikungunya fever – 337 clinical cases – in north-east Italy in 2007. The World Health Organization suggested that this outbreak may have been caused by climate change, but this was clearly injudicious. *Aedes albopictus* is a competent vector of the virus, it is abundant in the region where transmission occurred, the virus was a strain that appears to be specially adapted to this species, and all infections were traced back to an index case, a man who developed a febrile illness on the day after he arrived from India.

It is illustrative to summarise the background to this outbreak, because it was directly attributable to two modern transport systems – containerised freight and air travel:

- a Japanese mosquito was exported to the United States in used tyres, packed in freight containers
- the mosquito became established in the United States, first in the southern states and later as far north as Chicago
- the mosquito was exported from the United States to Europe, again in used tyres packed in freight containers (the initial infestation in Italy has now spread as far south as Sicily, into the Adriatic, and to France [including Corsica], Spain and Switzerland)
- Chikungunya virus emerged from its sylvatic cycle somewhere in Africa, quite possibly along the Lagos-Mombassa highway (This highway is part of the trans-African highway project, an ambitious venture to promote trade along 57,000 km of road throughout the length and breadth of Africa. More than half of the network has already been built: a coastal route circumnavigates western Africa from Cairo to Lagos; an east-west road is complete from Dakar to Ndjamena and will eventually reach Djibouti; a trans-Saharan road from Algiers to Lagos is nearly complete, another will run from Tripoli to Cape Town via Kinshasa and a third from Cairo to Cape Town. The main trade along all these roads is, of course, in freight containers. The potential for the dispersal of exotic species is enormous, and will grow with the success of the project. The prospect of Rift Valley fever traversing the Sahara, for example, is now very real, as is the possibility of establishment of important malaria vectors, such as *Anopheles gambiae*, in the Maghreb.)
- major urban epidemics occurred in Mombassa and Lamu, on the Kenyan coast

– further epidemics flared up on Indian Ocean islands: the Comoros, La Réunion, Mauritius, Madagascar and the Seychelles; the virus in these outbreaks was almost certainly introduced by air travellers (The epidemics in Réunion and Mauritius were transmitted by *A. albopictus*. The strain of virus involved appears to have a special affinity for this mosquito. The mosquito itself is not native to these islands; it was imported in ships from Asia at least a century ago.)

– an epidemic described as a major public health disaster, with several million cases, erupted in India (The virus may have been introduced by a traveller from Mauritius, for there are close cultural and commercial connections between the two countries.)

– a pandemic ensued throughout the Indian sub-continent, much of Southeast Asia, Indonesia and the Philippines

– an infected person flew from India to Italy

– epidemic transmission was initiated in two contiguous villages, Castiglione di Cervia/Castiglione di Ravenna, that are situated on land reclaimed from the delta of the Po River, formerly a notoriously malarious region.

## Conclusion

In 1988, the federal employees who had laboriously searched for mosquitoes in container-loads of Asian used tyres (2) wrote:

‘*Aedes albopictus* has joined the housefly, the flour beetle, the cockroach, the Mediterranean fruit fly, the yellow fever mosquito and many other insects that have vastly extended their range by virtue of their association with mankind. Time will tell whether *A. albopictus* also joins the list of exotic vectors that transmit human or animal pathogens.’

*Aedes albopictus* has indeed joined the list, and the enormity – or rather, the impossibility – of effective interception makes it evident that, with a few exceptions – e.g. the enforcement of vaccination requirements – the world must accept the continued dissemination and establishment of exotic species and pathogens as an inevitable consequence of modern transportation technology.

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## Le conteneur de fret normalisé : un vecteur pour les vecteurs et les maladies à transmission vectorielle

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### Résumé

Le fret par conteneur normalisé a été l'une des grandes innovations du xx<sup>e</sup> siècle. Il permet de transporter des marchandises par voie maritime, routière et ferroviaire depuis le point d'origine jusqu'à celui de destination, sans rupture de charge. C'est essentiellement grâce à ce concept simple que le transport maritime et terrestre est devenu aussi rapide et bon marché, donnant lieu à la croissance phénoménale du commerce mondial que nous connaissons aujourd'hui. De même, l'utilisation des conteneurs pour le fret aérien a considérablement accru le volume des transports intercontinentaux de marchandises, y compris de fleurs, de fruits et légumes frais et d'animaux vivants.

Dans les deux cas, le recours aux conteneurs offre de grands avantages en termes de rapidité et de sécurité des transports ; en revanche il réduit la possibilité de procéder à l'inspection des marchandises en transit. L'une des conséquences inévitables de cette évolution est la propagation mondiale d'espèces indésirables d'animaux, de plantes et d'agents pathogènes. En outre, les vols aériens à bas prix facilitent la propagation des virus et autres pathogènes hébergés par des voyageurs infectés. L'émergence ininterrompue de nuisibles, de vecteurs et d'agents pathogènes exotiques partout dans le monde est la conséquence inévitable du progrès technique enregistré dans le domaine du transport.

### Mots-clés

*Aedes albopictus* – Cargo – Chikungunya – Conteneur – Conteneur de fret – Fret aérien – Mondialisation – Transport – Transport maritime.



## El contenedor de carga normalizado, vector de vectores y de las enfermedades que transmiten

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### Resumen

El contenedor de carga normalizado fue una de las más importantes innovaciones del siglo xx. Dentro de esos contenedores el cargamento viaja desde su punto de origen hasta su destino por mar, carretera y ferrocarril como parte de un trayecto único, sin ruptura de carga. Este sencillo concepto es el elemento clave de un transporte rápido y barato por tierra o por mar, y ha propiciado un crecimiento formidable del comercio mundial. Análogamente, el uso de contenedores por vía aérea ha conducido a un notable incremento del transporte intercontinental de bienes como flores, frutas y hortalizas frescas o animales vivos.

En ambos casos, el uso de contenedores ofrece grandes ventajas (más velocidad y seguridad), pero reduce la posibilidad de inspeccionar los cargamentos en tránsito. Consecuencia inevitable de ello es la extensión mundial de especies indeseables de animales, plantas y patógenos. Además, los vuelos baratos de pasajeros ofrecen a los patógenos víricos y parasitarios un medio idóneo para viajar por el mundo a bordo de personas infectadas. El continuo advenimiento por todo el planeta de plagas, vectores y patógenos exóticos es un efecto inevitable de esas ventajas ligadas a las técnicas de transporte.

#### Palabras clave

*Aedes albopictus* – Cargamento – Chikungunya – Contenedor de carga – Contenedores – Mundialización – Tráfico marítimo – Transporte – Transporte aéreo de mercancías.



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