Cost Benefit Analysis Unmanned Cargo Aircraft: Case Study Stuttgart - Urumqi/Shenzhen

Master's Thesis Erasmus University Rotterdam

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Introduction

Air cargo roughly accounts for one percent of world trade calculated by tonnage, though it represents about 35 percent of the world trade calculated by value of the goods that are shipped (Boeing, World Air Cargo Forecast 2014-2015, 2014). That is not a surprise since the cargo transported by aircraft generally consists of high-value goods that need to enter their market as fast as possible (The World Bank, 2009). Hence air cargo is an expensive mode of transport, yet in a globalised world in which more and more goods need to be delivered just in time, the role of air transport is increasingly important (Zhang A. , 2003); (Boeing, World Air Cargo Forecast 2014-2015, 2014). Currently air cargo travels either by full freighter, combi aircraft, or in the belly of passenger jets, meaning that in order for air cargo services to be profitable either high volumes of cargo need to be imported and/or exported by a particular region around an airport or passengers have to be interested in visiting that same region. One way to connect regions lacking these characteristics to the global world and create a better competitive position for them, could be a more cost efficient mode of transport, one that still needs to be developed.

Unmanned cargo aircraft (UCA), also named Unmanned Aerial Vehicles (UAV), may perhaps represent a mode of transport that makes cheaper and more efficient air cargo transport possible for regions that are currently not connected to the global world by a direct connection, meaning that one or more transfers are necessary to get there. Reasons are mentioned by Hoeben (2014) and (Prent, 2013), and range from costs savings from the crew, to lower fuel costs and more flexibility in flight schedules. Yet so far, though there are prototypes of UCA, a chicken and egg situation exists. The UCA are not built and do not operate yet since it is not clear to airlines whether it is beneficial to start operating them, on the other side aircraft manufacturers do not build and sell UCA since airlines or private companies do not show enough interest. To break this cycle, more research must present a realistic prediction of the feasibility and potential benefits of UCA in the near future. This thesis aims to find an answer to the question whether or not and to what extend the UCA would be beneficial and cost-effective to operate on long-haul routes. The feasibility of UCA will be analysed by conducting a case study.

The case study will be conducted on routes with no regular and direct air cargo traffic yet, though connected to the world by ship, rail, road or a combination of these modes and air cargo. Regions not served by (cargo) airlines that currently have to transport their goods via several modes of transport or barely export at all might benefit from the faster and likely to be cheaper mode of transport of UCA. The case study of this thesis will be between Stuttgart and Shenzhen and Stuttgart and Urumqi. Chapter one will picture the current situation of the global air cargo market using the available literature and other market information such as reports from Boeing, Airbus, and The World Data Bank. After that the whys and wherefores of UCA being a possibly more beneficial mode of transport in some cases will be stated in chapter two, also including the limitations. Chapter three will elaborate on the methodology whereas chapter four enlightens the regions chosen for the case study, including a market analysis and forecasting for the air cargo market in the specific regions and which type of UCA would be suited best. Subsequently chapter five explains the value analysis mainly using the model of Hoeben (2014). Finally chapter six will present the discussion of the results including the bottlenecks that need to be overcome to implement UCA. Chapter seven entails the conclusion.

Chapter 1 – Market Analysis Air Cargo

For a good understanding of the air cargo market and what role UCA would play herein, this chapter elaborates on the types of goods, the logistic network, and the trends of the worldwide air cargo market. Section one depicts a general picture of the world market, section two explains the type of goods that are transported by air, section three indicates the logistic network, and section four depicts the recent trends. Taking together the information of the four sections, section five will conclude in what situation UCA will generally operate.

1.1 Air cargo in general

'Air cargo enables nations, regardless of location, to efficiently connect to distant markets and global supply chains in a speedy, reliable manner' (Kasarda & Green, 2005, p. 459). In 2013 the total world air cargo market consisted of 208 billion RTK (one tonne of revenue freight carried one kilometre), of which 131 billion RTK was long-haul air cargo, flying on routes longer than 4,500 kilometres (Boeing, World Air Cargo Forecast 2014-2015, 2014). Demand for long-haul air cargo is largest for Europe-Asia (31 percent) and Asia-North America (34 percent), the other 25 percent goes either between Europe and North America or on other long haul routes (Boeing, World Air Cargo Forecast 2014-2015, 2014). This results in nearly 80 percent of long-haul air cargo traffic flowing on east-west trades. Besides these east-west trades, demand for air freight exports has been limited from less developed countries in which most enterprises generally only ship small volumes of lower value goods (The World Bank, 2009). Indicating that smaller markets currently have less access to air cargo than large markets, reasons for this could be the high prices for transport and the type of goods transported, which will be depicted in the next section.

1.2 - Type of goods

Low value goods rarely travel by aircraft due to a cost restriction, air freight costs are typically four to five times that of road transport and twelve to sixteen times that of sea transport (The World Bank, 2009). Transporting goods from China to Europe by rail instead of air will save about 70 percent of the transport costs (Cargo From China, 2016), making air freight costs about 3 times more expensive than trains costs. Accordingly, due to the high costs, commodities shipped by air usually have high values per unit and/or are very time-sensitive (The World Bank, 2009), examples of goods are documents, pharmaceuticals, fashion garments, production samples, electronics consumer goods, and perishable agricultural and seafood products. Also spare parts and emergency shipments are mostly shipped by air (The World Bank, 2009). On top of that, one can notice a difference between the types of goods imported and exported. The main goods imported from developing countries by developed countries are cut flowers, electronic parts, and fresh fruits and vegetables, whereas high value consumer goods fly the other way around (The World Bank, 2009). Lacking a significant outbound flow for developing countries, the inbound freight rates are higher, which reduces the types and quantities of goods transported by air (The World Bank, 2009). This results in a typical logistic network, described in section 1.3.

1.3 - Logistic network

The globally logistic network consists of three modes that transport cargo intercontinentally. This section names all three, though with a focus on the role of air transport and the way air cargo transport currently operates. This helps to determine how UCA would operate and possibly increase the efficiency within the current logistic network. As mentioned in the previous section, most goods transported by air are high value goods that need to enter their markets as fast as possible. However, next to the type of goods transported, the globally integrated 'just in time' production and distribution systems also contribute to the strong interests in the air-cargo industry (Zhang A. , 2003).

Air transport is one of the three choices for intercontinental freight transport, offering the benefits of speed and reliability (Boeing, World Air Cargo Forecast 2014-2015, 2014). Another mode is maritime which offers the primary benefit of low cost (Boeing, World Air Cargo Forecast 2014-2015, 2014). Whereas the other option is by train, evidently only between connected continents, which is in the middle of the former two with respect to time and costs. When a company is transporting goods there are practically three approaches. Companies can arrange their whole logistics network internally and contact the carriers, such as the (cargo) airline, without any intermediaries. This usually only happens within multinational companies. Opposite and secondly, companies can ask a large logistic company like UPS or DHL to take care of their whole transportation network. The companies they approach, or have partnerships with, offer in that case full logistic services. A combination of the former to ways is a third option.

Transporting by any of the three approaches just mentioned, cargo used to fly via- and transfer at Hub airports. Similar to passengers, most movements were in a so called Hub-and-Spoke network. However, again similar to passengers, the trend is currently moving towards point to point delivery. Though that does not mean most cargo currently flies point to point, actually cargo often flies an 'illogical' detour (Zhang & Zhang, 2002) as it does not complain to fly a couple of hours extra. Besides, it often happens that cargo is trucked under freight consignment note, in this case cargo trucks feed the (hub) airport with 'air cargo' (van de Voorde & de Wit, 2013). On top, air cargo, though also general cargo, usually travels only one way. Meaning that many of the trade lanes in the world are not balanced directionally (Zhang & Zhang, 2002) (Boeing, World Air Cargo Forecast 2014-2015, 2014). With respect to imbalanced trade routes, UCA could offer a solution being flexible and not having the need to fly returns. With not having a crew with a 'home base', the aircraft can for instance make a roundtrip, as will be elaborated on in chapter 2. Currently, with manned aircraft, these unbalanced trade routes are especially unprofitable for combi aircraft or full freighters, not having a large share of passengers compensating for the lack of cargo.

Air cargo is transported in either full-freighters, combi-aircraft, or in the belly of the passenger aircraft (Zhang & Zhang, 2002). In 2013, 57 percent of annual ATKs (the number of tonnes carried multiplied by the number of kilometres flown) worldwide was transported in belly hold of passenger aircraft, one percent in combi aircraft, and 42 percent in full-freighters (Boeing, World Air Cargo Forecast 2014-2015, 2014). A standard narrow body full freighter can carry up to 45 tonnes, a medium wide body 40-80 tonnes and a large wide body freighter up to more or less 100 tonnes (Boeing, World Air Cargo Forecast 2014-2015, 2014). The belly of a medium sized aircraft can transport more or less 15 tonnes and up to 25 tonnes in a large wide body, depending on the passenger load (Emirates, 2016). According to Boeing (2014) and Airbus (2015) more freight is transported by medium-wide body than large body aircraft. In what aircraft air cargo is transported depends on the demand and supply of a region, both in terms of cargo and passengers. This indicates that in general either demand for air cargo must be significant filling up a medium-wide body aircraft carrying about 40 to 80 tonnes, or the region must attract passengers and the aircraft can transport about 15 tonnes in a medium-wide body.

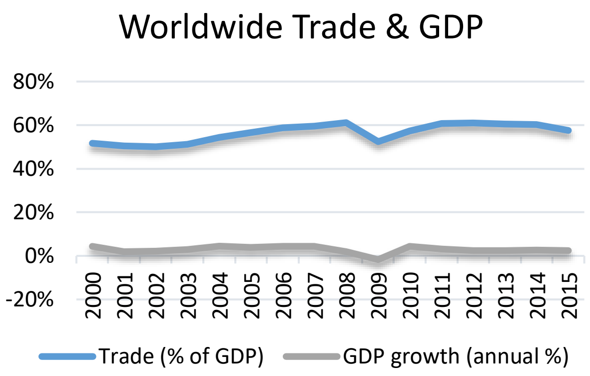
For many undeveloped or developing regions neither large cargo or passenger demand is present, in that case UCA transporting smaller amounts of cargo beneficially could be a solution for these regions. On both transporting smaller amounts and why this can be done beneficially will be elaborated on in chapter 2 and 4. In the case of air cargo being transported in combi aircraft or passenger aircraft the capacity for cargo is variable due to the uncertainty about the number of passengers and baggage carriage (Moussawi-Haidar, 2014), which makes it more difficult to anticipate on demand. However the risk of no shows is higher with air cargo than with passengers. Instead of simply transporting one passenger on one seat, capacity is measured by weight and volume and is likely to be a lot larger than one seat (Moussawi-Haidar, 2014), meaning that a no-show could be a 20 percent empty flight instead of one passenger not showing up, often being less than 1 percent[1] of your flight. Compared to passengers, cargo creates significantly higher revenues on intercontinental flights. An analysis of Schiphol Airport reveals that transporting airfreight on international flights results in a revenue of on average 40 euros per passenger, resulting in an operational marge of about 15% points (Kuipers, et al., 2007).

Concluding, the current logistic network in which just-in-time is more and more important shows more interests in fast and reliable transport instead of slow and cheap transport. For that type of transport air cargo is the most obvious solution. Most air cargo is transported in either medium-wide body passenger aircraft or medium-wide body full freighters which offer respectively about 15 tonnes or 40-80 tonnes. Filling up a standard full freighter requires a lot of demand, though transporting by passenger aircraft brings along more uncertainties with respect to available space. UCA could offer a middle solution by being a cheaper and flexible mode that does not require too much demand. More precisely it offers the advantages and flexibility of a full freighter, though the capacity of the belly of a passenger yet, while being cost efficient due several advantages of unmanned versus manned. Chapter two will elaborate on the advantages of UCA, the next section will continue with the current trends of air cargo.

1.4 - Trends

Since 1983 world air cargo traffic has averaged 5.2 percent growth per year (Boeing, World Air Cargo Forecast 2014-2015, 2014). From mid-2011 to early 2013 word air cargo stagnated and is believed to have followed the decline in traffic associated with the global economic downturn of 2008 (Boeing, World Air Cargo Forecast 2014-2015, 2014). By July 2014, traffic had grown 4.4 percent compared with the first seven months of 2013 and is expected to keep growing by this rate for the next 20 years (Airbus, 2015) (Boeing, World Air Cargo Forecast 2014-2015, 2014) Worldwide airfreight for the past 15 years is depicted in Figure 1, the trends mentioned by the reports of Airbus and Boeing are confirmed by this graph.

[1] Less than 1% taking the most popular medium wide body, a Boeing 737 or Airbus A320, with 150 to 180 passenger seats into account.



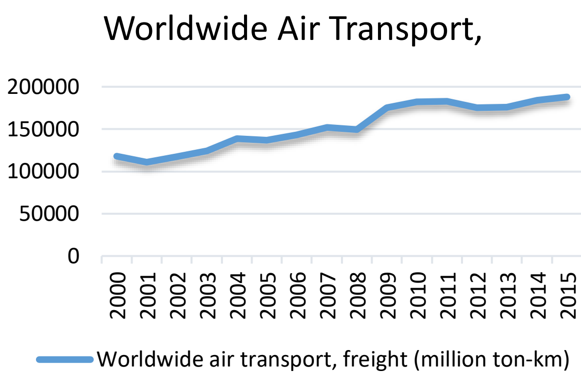


FIGURE 1 & 2 - WORLDWIDE AIR FREIGHT TRANSPORT & TRADE
SOURCE: WORLD DATA BANK

Literature indicates that economic development and air cargo show a positive relationship. Besides, air cargo volume is positively linked to GDP (Kasarda & Green, 2005). Keeping in mind that nothing can be said about causality, air cargo volume is measured to be strongly linked to trade growth (Zhang & Zhang, 2002), and growth of trade value is positively linked to GDP (Kasarda & Green, 2005). These trends are visualised in figure 1 and 2 above. Correspondingly the world bank indicates that the use of airfreight can create a competitive advantage for the region around the airport (The World Bank, 2009). The causality from air traffic to growth is seen for regional growth in peripheral regions, but this causality is less evident in core regions (Mukkala & Tervo, 2013). Although it is not proven that the causality starts with this competitive advantage that creates trade growth and with that results economic development, it should be this way around for air cargo to affect economic development.

Many developing countries are not able to create the competitive advantage mentioned in the previous paragraph and have relatively limited air transport services because of their small size and low level of economic activity (The World Bank, 2009). Besides, since most cargo flies in the belly of passenger aircraft, countries with low cargo volumes and low interest for tourists or other travel reasons, are facing difficulties in making the transition to the fast moving air cargo market and thus global trade of goods. Though for countries that are interesting for tourism (only), the need for traffic is driven by passenger traffic growth rather than freight traffic growth (Airbus, 2015). If this passenger driven growth is created by tourism, this means that only during tourist season extra capacity is available (The World Bank, 2009). This might lead to capacity difficulties if the demand for cargo remains stable throughout the year. Hence because of the addition of larger and more capable passenger aircraft, increasing the underfloor space available for freight operations, the market share for belly capacity is expected to continue to grow in the future (Airbus, 2015), this growth is especially expected on the long-haul inter-continental routes (Airbus, 2015).

With respect to trends it is visible that air cargo is continuously growing and yet expected to keep growing in the future. However, the market seems to skip the less developed regions not having enough economic activity nor attractiveness for tourism. Those regions could enter the global world by the use of UCA.

1.5 - Concluding remarks

It is apparent that air cargo currently is an expensive mode of transport though very useful for high value goods or goods flowing in a 'just-in-time' supply chain. Hence regions with not enough freight volume or attractiveness for passengers can hardly enter this fast moving market with their high-value goods and therefore have a less competitive position opposed to regions that are better connected to the global world. Besides, even though the hub-and-spoke network is moving into the direction of a point to point network, most cargo still flies a detour to its final destination, leading to more transfers or longer routes. Moreover, smaller regions are also in the point to point network not directly connected to possible demand regions. For these smaller regions to enter the world market with their time-sensitive goods, the air transport market should become cheaper and more flexible. The next chapter will present UCA and why it can be expected that this type of aircraft could make this possible.

Chapter 2 – UCA

Though UCA are relatively new in aviation, numerous institutions are designing prototypes of unmanned vehicles, most not in operation yet. Some (futuristic) pictures are shown in appendix 5. Hence these aircraft are not built nor operating at the moment, nevertheless a handful of studies did already form a basis for further research on UCA and their feasibility. This chapter will elaborate on the characteristics, benefits, and limitations of UCA, including an overview of existing research on their practicality. The first section depicts the existing literature, after which the characteristics will be addressed in section 2. This section is divided in a segment displaying the advantages (2.2.1) and a segment displaying the limitations (2.2.2). An overview of the characteristics is given in the conclusion, visualised in a table.

2.1 – Literature Unmanned (Cargo) Aircraft

In general terms, an unmanned aircraft (UA, or UAV: Unmanned Aerial Vehicle) is an aircraft which is intended to operate with no pilot on board (ICAO, 2011). Hence a UA is often better classified as an RPA, remotely-piloted aircraft, which is controlled by a licensed “remote pilot” situated at a “remote pilot station” located external to the aircraft (ICAO, 2011). The potential of unmanned aircraft in civil use has long been evident and is beginning to be realized for applications that are dull, dirty or dangerous (ICAO, 2011), hence a broader scope for UA include commercial, scientific and security applications, uses that mainly involve monitoring, communications and imaging (ICAO, 2011).

The uses described by (Nonami, 2007) include mainly science observation and agricultural chemical spraying, though these types of UA are usually very small and the machine ways only up to 30 kilograms. Other than that, the present-day use of UA is mainly for military purposes (Hoeben, 2014). Evidently unmanned technology has already proven itself within military aircraft, though the technology is also widely seen in large aircraft in civil use, as the currently operating passenger and cargo aircraft are estimated to fly 90 percent of most flights on the autopilot (Cox, 2014). However, large UA’s for civil operations are not in use yet. One of the civil purposes of a (large) UA can be transporting cargo, an unmanned cargo aircraft, from now on addressed as UCA.

It is important to keep in mind that the type and size of UCA analysed in this thesis is close to a small manned aircraft and therefore not quite comparable to the, more written about, drones that can carry only a few kilograms. To this day not much literature is available that examines the (economic) feasibility of operating UCA, which is understandable since this type of aircraft is not in operation yet. The pioneer articles that presented the first analyses of UCA are those of Lugtig and Prent (2011), Kremers (2012) and Hoeben (2014). Lugtig and Prent (2011) presented a model for a costs analysis of UCA compared to all other modes of transport on short-haul distances in Europe. The paper concludes that a UCA carrying 3.5 tonnes costs 0.97 US dollars per tonne per kilometre transported on a short-haul distance, be it for the assumptions made in this analysis. Results for road ($0.18), train ($0.16), and shipping ($0.01) were lower in terms of costs. Manned cargo aircraft were slightly more expensive with $0.98 per tonne per kilometre transported.

Short-haul distances were also analysed by Hoeben (2014) who performed a value analysis on the unmanned aircraft operation of high time value cargo compared to regular (large) cargo aircraft in the United States of America. The results of this thesis indicate that the added value of UCA can reach up to five per cent of the total logistic costs in the predicted demand scenarios of short distance routes. Whereas the added value for long-haul distance was estimated to be two per cent. As Hoeben (2014) focussed on high-time value cargo flying long-haul on transatlantic routes only, the comparison of UCA was only made with regular cargo aircraft. Therefore the costs savings presented in this thesis are with respect to aircraft on the exact same route, not to other modes of transport. Furthermore, the comparison was to relatively large cargo aircraft, which is expected to be less beneficial than to smaller aircraft, as costs are spread over a larger share of freight. This indicates that UCA are not likely to be beneficial (enough) for short-haul routes in the near future, yet the long-haul routes might be more promising, when comparing them with other modes of transport and for other than airport-to-airport air cargo routes.

An analysis of long-haul intercontinental cargo of UCA compared with all other modes of transport has not been conducted yet. Hence Kremers (2012) came up with a model that can take all other modes of transport into account in a benefit analysis, yet did not apply this model to a (long-haul) case study. Even though this model is extensive and includes a lot of useful details to take into account, the time sensitivity for goods is not included. Meaning that these results give a clear overview of the real costs of transport, yet not taking into account the types of good transported. Consequently such an analysis, including the reals costs of transport, seems like a logical and useful next step in the development of UCA research. For this matter the model of Hoeben comes in very handy.

Concluding, two of the three papers mentioned present a case study on short-haul routes. Results came out positive, yet very small, in favour of UCA compared to manned aircraft. The model that is developed for long-haul routes is useful though does not take into account the time sensitivity that is, as explained in chapter one, very relevant for high value goods. The models can be applied to different types of UCA and aircraft, whereas the methodology of this thesis will be discussed in chapter three, the characteristics of the UCA taken into account will be described in the next section.

2.2 – Characteristics

In this thesis a UCA is an aircraft transporting goods without any pilot on board, the existing literature described in the previous section, has formulated a number of characteristics of UCA which will be explained in this section. The characteristics are described in two parts, starting with the benefits and ending with the limitations.

2.2.1 - Benefits UCA

Several benefits, which essentially lead to costs savings, arise when flying cargo with unmanned aircraft. These benefits include lower crew costs, a cheaper and lightweight airframe, optimised airframe for cargo handling, costs savings due to the flexibility of the aircraft, improvements with respect to sustainability and the ability to land at industrial parks. Each advantage will be described in a separate section.

2.2.1.1 – Lower crew costs

A first and obvious cut back in costs of an unmanned aircraft is the elimination of the crew, as the aircraft will be controlled by only one pilot on the ground, who can control up to 12 UCA simultaneously (Cummings & Guerlain, 2007). With only one (remoting) pilot, who in fact counts for less than one (1/12th), it is obvious that labour costs will be substantially lower compared to at least two pilots (one pilot crew), or two pilot crews on board when flying more than 10 hours (GPO, 2016). During take-off and landing the remoting pilot should focus on only the aircraft about to undertake one of these actions. Hence one hour per flight should be remoted by one pilot only focussing on that flight. Remoting pilots will be named UCA controllers in this thesis.

2.2.1.2 – Lightweight, cheap and cargo-optimised airframe

Whereas an unmanned aircraft might sound more complicated than a manned aircraft, these aircraft can essentially be less complicated. Due to the fact that there are not any pilots on board, no extensive cockpit nor a pressurized cabin are needed in the aircraft. Besides, other than doors to load cargo, no windows, passenger doors and other passenger related equipment such as toilets or seats are needed. Neither life-saving equipment is necessary and possibly there is no need for regular fire extinguishers. With no passengers on board, filling the cargo compartment with nitrogen could be sufficient to protect against fire or explosion (Kremers, 2012), however this latter point is not proven yet. All together this can lead to an airframe that is relatively 20% more light weight than a similar size manned aircraft (Hoeben, 2014), which leads to lower fuel consumption. Yet another advantage of a lightweight airframe is less costs for equipment on board resulting in lower maintenance costs.

Furthermore, the aero dynamical shape can be optimised, including an optimal design for transporting cargo. Possibly with (square) containers that are part of the airframe, as the airframe can take on a rectangular shape. Hence with a cabin that is not pressurised there is no need for a round cabin. Furthermore an optimal design for cargo includes doors that are optimally situated in for example the nose and tail of the aircraft (Kremers, 2012). Henceforth each time the aircraft operates one can notice the benefits of the probably faster handling time at the airport. Yet as will be explained in section 2.2.1.5, UCA do not need to pass by airports. Other characteristics of UCA can vary per model, similar to passenger aircraft many types can exist. Hoeben (2014) incorporated several UCA types in his model, differing in max payload and cruise speed. The type of UCA considered in this thesis will be presented in chapter 4.2.

2.2.1.3 - Flexibility

Not having a crew on board leads to fewer limitations in flying and therefore increasing the flexibility (and the arising productivity) of the UCA, subsequently leading to costs savings. A first advantage, with no crew on board that needs to return to a home base, is that there is no need for return flights which makes the routing of the aircraft considerably more flexible. Besides, idle time at an 'away' airport due to a crew that needs rest can be eliminated, which means that the aircraft can be utilised to its maximum, making it more productive. Moreover, it is possible to have a flight duration as long as desired, only being restricted by fuel and thus not being dependent on a crew that needs rest. Specifically this means the unmanned aircraft can fly at any time as long as it needs to, while only needing to land to refuel. As fuel is the only restriction, the UCA can fly somewhat slower (which again saves fuel). On top, by flying slower the aerodynamic forces on the aircraft are lower, which is another reason the UCA can be constructed more lightweight (section 2.2.1.2). However the flexibility of flying slower also affects the emissions of the aircraft, as explained in section 2.2.1.4. Flexibility also increases as the UCA do not need to land at airports, see section 2.2.1.5.

2.2.1.4 – Sustainability

As the previous section described the UCA will be flying slower, a result of this is flying at lower altitudes, which is more efficient with relatively cheaper and less polluting turbo probs. Besides, nitric oxide and nitrogen dioxide (together NO_x) are less harmful at lower heights as they affect the ozone significantly more when they are emitted close to it (Schumann, 2000). On top of being less polluting when it comes to NO_x, it is obvious that also CO_2 emissions are lower as less fuel is burned. With sustainability gaining importance in the development of companies' business strategies in the transport and logistics sector (Oberhofer & Dieplinger, 2014), this can be seen as an advantage on top of the lower costs for fuel.

2.2.1.5 – Landing directly at industrial parks

UCA need that little infrastructure that when legislation would allow them, they are able to land on (at night) empty roads at industrial parks or small airports close to these areas (Kremers, 2012). Landing at industrial parks is possible due to another factor concerning the optimal aero dynamical shape. Straight wings allow landing at very low speeds which makes landing at relatively short stripes of asphalt possible. On top the approach can be very steep, there is no need to lift the nose of the aircraft (flare) and braking at short distance is possible. Landing at the destination of origin or final destination gives several advantages. Firstly, transferring (especially at airports) takes a lot of time. Besides, also with respect to time, it is most efficient as the cargo does not need to be transported by truck or rail from the industrial park to the airport and vice versa. That brings another advantage along with respect to handling, every time cargo is (un)loaded the risk of damage is present. By decreasing the number of transfers of modes of transport, this risk of damage will be minimized. Lastly, airport charges can be skipped as much as possible. However the UCA must still fly by for refuelling, yet this is possible at the smaller (and cheaper) regional airports.

2.2.1.6 – Concluding remarks benefits

With respect to the benefits of UCA it can be concluded that with regard to the cheaper and more lightweight airframe, lower labour costs, more flexible operations, good score on sustainability, design for handling cargo, and the little infrastructure needed it can be expected that the aircraft can operate highly efficiently at lower cost. Hence the application would be that, especially when the size of the UCA would be chosen to be smaller than regular cargo aircraft, smaller (demand) regions can be directly connected to each other instead of the cargo moving via one or more hubs. Leading to a faster delivery time for these regions and a smaller chance of losing or damaging the goods (Kremers, 2012). Chapter four will elaborate on the exact type and size of the UCA analysed in this thesis. However, for any type of UCA, some limitations must be overcome to realise their operations. These will be described in the next section.

2.2.2 – Limitations UCA

Even though all benefits described above indicate that costs can be saved on almost all aspects of a UCA compared to regular aircraft, research must specify whether the benefits of cheaper yet still fast transportation would also outweigh the slower and much cheaper modes of transport. Yet even in the case that research would prove UCA can be beneficial in certain situations, several obstacles must first be overcome. Whereas the technological step of unmanned aircraft is quite small, manned aircraft can be transformed relatively easy to an unmanned aircraft by only installing special guidance and control equipment (Hoeben, 2014), there are some obstacles to overcome that will be described in this sections. The obstacles include the rules and legislations, reluctance to invest and the developments in hacking and hijacking.

2.2.2.1 – Legislation

For UCA to start operating the legislations for its operations must first be changed. Especially around airports the rules and legislation for unmanned aircraft are very strict and they are currently banned from these regions, though rules concerning this matter are currently mostly focussed on small unmanned vehicles (drones). Another problem to be solved related legislation are the responsibilities in case of accidents, it must be made very clear who is responsible when something occurs and to what extent legislation allows the UCA controller, not being on board of the aircraft, to be responsible. On top, even though research says one controller can control up to 12 unmanned aircraft, the discussion on how many UCA per controller is still going on.

2.2.2.2 – Reluctance to invest

The willingness to invest must be present for UCA to enter the market. However, parties that are likely to invest, such as airlines, might be reluctant to do so. The public might find the idea of aviation moving more and more towards autonomous transport scary. Hence investing in unmanned vehicles might hurt their image as this investment could rise the perception of people that this will happen with passenger aircraft soon as well. On top, the first one invest must completely pave the way. Rather expensive (research) investments must be conducted into matters such as training the UCA controllers, setting up the stations, and determining demands for the necessary infrastructure.

2.2.2.3 – Hijacking

When UCA would start operating, software needs to be developed or purchased to protect against hacking and hijacking. Even though there is no direct proof or reason to expect that the controlling (remoting) system is likely to be hacked, it must be something to keep in mind. As the aircraft will be transporting high-value goods, criminals might find interest in hijacking the aircraft to steal these goods. With no pilot on board, it might be more difficult to protect against such hacks.

2.2.2.4 – Concluding remarks limitations

The largest limitation for UCA is the legislation and the rules of the aircraft to operate. That could be, together with the first mover costs and effects on image, a reason to be reluctant to invest. Hence when those two limitations are overcome, one keeps existing, which is the possibly higher risk of hijacking. With no pilot on board it might be more difficult to take back control of the hacked UCA.

2.3 - Concluding remarks

The benefits and limitations, and their effects on operations, of UCA are displayed in the table below. In words one can say that the advantages mentioned in this chapter, with respect to long-haul flights, are all related to *the effects of* no crew on board. Some costs on the crews' salary will be saved, but especially the added productivity and efficiency of the aircraft are likely to be beneficial. The routes and times, both flight time and departure times, are more flexible. As well fuel can be saved by flying slower and, as long as it doesn't cause too many problems, the aircraft can be optimally designed for transporting cargo. Including a lightweight construction and no lifesaving equipment. The latter two points also positively relate to the sustainability matter, making aircraft having less negative impact on the environment. Lastly, the infrastructure needed for these aircraft is very limited, making it possible for UCA to land on industrial parks. However, this last advantage touches up on the largest limitation of UCA, legislation does currently not allow to have aircraft flying (or landing) just anywhere. Especially around airports unmanned vehicles are prohibited. The benefits and limitations are depicted in the table below, as flexibility and faster transport will be measured in costs it is logical that an improvement on those will result in costs savings.

Effects of the Benefits UCA	Costs Savings		Contributing to Flexibility		Transport time		Limitations to overcome
No Crew on board	✓	Labour costs	✓	No 'home base'	✓ ✗	Depends on the destination	Legislation, Reluctance to investment, Protect against hijacking
More light weight Airframe	✓	Fuel costs	✓	Able to land on short runways or roads	✗	Flying slower	No limitations
Cheaper Airframe	✓	Maintenance	✗	No impact	✗	No difference other than previous point	Unknown what the airframe should look like
Flexible operations	✓	Efficient routing Less idle time	=	(same point)	✓	Efficient	No limitations
Sustainability	✓	Lower altitudes *(less harmful NO_x)* Less fuel *(less CO_2)*	✗	No impact	✗	Flying slower	No limitations
Optimised design cargo handling	✓	Less damage and handling time	✓	Easy handling	✓	Faster handling	No limitations
Little necessary infrastructure	✓	No airport charges Less transfers	✓	Able to land in industrial parks	✓	Able to land at final destination > less transfers	Legislation (allowing to land)

Chapter 3 – Methodology

So far it has been indicated why and how UCA could be a mode of transport that makes cheaper and simultaneously fast cargo transport possible in certain scenarios, and why this is relevant. As the literature indicates, UCA are most likely to be beneficial on long-haul routes. Though it is yet to be analysed if they would be able to outperform all the other available and existing modes of transport. Specifically, this thesis aims to find an answer to the following question: "*To what extent are UCA beneficial and cost-effective to operate on long-haul routes, compared to all possible modes of transport?"* In order to answer this question it is necessary to define which routes and types of goods will be analysed and explain why these might be attractive for UCA to fly on. Besides it is essential to name the other possibilities on these routes in terms of transport modes and display their advantages and disadvantages. The main question and subsequent sub questions are displayed in figure 3 below.

Main Question	**"To what extend are UCA beneficial and cost-effective to operate on long-haul routes, compared to all possible modes of transport?"**	
Question 1	"How can the transport costs of UCA be determined?"	Chapter 3
Question 2	"On what long-haul routes can it be expected to be beneficial to operate UCA?"	Chapter 4
Question 3	"What is the current and future demand for Air Cargo in this case?"	Chapter 4.1
Question 4	"What are the current modes of transport and what are their characteristics/costs?"	Chapter 4.2

FIGURE 2

3.1 – Scope

In this thesis the focus will be on long-haul routes on which air cargo does not fly directly yet, hence for cargo to get to that region it needs to travel by several modes of transport. Therefore not only air cargo, but all modes of transport will be taken into account for transporting the goods in the comparison. The option of not transporting goods at all is left out of consideration. To incorporate all modes of transport, two separate regions of which one is connected to an intercontinental rail network and another that is close to a sea harbour will be taken into account. This presents itself as a case study incorporating all costs and benefits of all the modes of transport between that region and a region in anther continent. Technically a UCA can land on a strip of asphalt in an industrial park, meaning that airports can be completely skipped. Realising that a great obstacle to overcome before this can come about is concerning the legislations, which could take a long time. However it is still assumed that the UCA can land on the final destination of the cargo, as this is how the UCA's are designed to operate in the future. The types of the manned aircraft, trains, and trucks the UCA will be compared to will be explained in chapter four. The types of goods that will be analysed are high-value goods that benefit from entering their market as soon as possible, their values and demand will also be depicted in chapter four. Before discussing these matters, this chapter will elaborate in the model and other calculations to analyse the transport costs. This thesis does not include import and export costs as a part of transport costs. These costs are dependent on the types of goods and not on the mode of transport. Hence they are assumed to be the same for all modes and thus not considered.

3.2 – Model for the Costs and Benefits Analysis

With respect to question 1, "How can the transport costs of UCA be determined?", it is important to use an honest and clear methodology to depict the costs of UCA. As mentioned in the literature review, Lugtig and Prent (2012) developed a model for a cost analysis of UCA whereas Kremers (2012) developed a model for the benefits analysis. However, the types of goods that will be analysed are high-value goods that benefit from entering their market as soon as possible. In this matter, an important addition must be made to these models, incorporating costs of goods during transit time (devaluation) that form the main reason why time-sensitive goods must enter the market as fast as possible. The model of Hoeben (2014) has taken this into account and will therefore be used as the guideline for this thesis. However the model of Hoeben (2014) only compares aircraft, meaning that this model must be modified to be useful for the other transport modes as well. All this by keeping it a simple as possible in order to keep all results easy to interpret and reproduce.

Specifically this means that the model of Hoeben will be used in order to come up with the total logistic costs function, furthermore a similar function will be developed for the other modes of transport, using information from the articles of Lugtig and Prent (2012) and Kremers (2012). Other articles that focussed on mainly shipping; van Hassel et al (2016), rail; Rastogi & Arvis (2014) or trucking; Barnes & Langworthy (2003) deemed very useful as well. Nonetheless all key elements of the model and most of the aircraft information[2] come from Hoeben (2014). Similar to this model, all variables will be used in a costs approach to express value, meaning that benefits, customer satisfaction, and costs are all related to a certain logistics operation and its corresponding time, and can thus be expressed in terms of monetary value. Furthermore, flexibility and the resulting productivity, and sustainability are included.

The benefits created by de productivity and flexibility of UCA will be included by calculating costs that other modes of transport make that are avoided by UCA. Therefore all costs are calculated per week and not just during transport time. The advantage of UCA arises as they can operate at any time needed whereas the other modes transport by a schedule. In that case goods will generally have to wait longer before transport is available. These costs also include costs during handling times. Besides, flexibility is included with departure times and avoiding airports, landing on industrial parks saves money in terms of airport charges. The possibility of circle trips instead of round trips will not be quantitatively analysed. Lastly sustainability will be included, which is also done by Kremers (2012), using environment taxes in his analysis. In this thesis sustainability will not be directly taken into account in the formula using environment taxes account as currently no direct costs exist on emissions. Hence these will be analysed in a separate section of chapter five.

Taking everything together the model can analyse and compare all transport costs, similar to Hoeben (2014) comparing UCA to manned aircraft. Unlike Hoeben, this thesis will not minimize the costs function, but will simply compare the different outcomes of the different modes of transport as they come out of the logistics costs function. After the cost function is calculated, the function will undergo a number of sensitivity analyses. Meaning that variables that have a great impact on the outcomes of the model, such as oil costs or different market demands, will be tested having different values. In this

[2] Information concerning costs are adjusted for inflation by a rate 1.6% in 2013, 0.8% in 2014, 0.1% in 2015 and 0.4% in 2016. All rates are based on the inflation in Germany according to Eurostat (Eurostat, Eurostatistics. Data for short-term economic analyses 12/2016, 2016)

case a threshold can be presented in what situation a UCA becomes beneficial. Lastly, since new markets may be able to enter the global market by the presented trade route, the model enables the analysis of current and future demand scenarios and compare these with manned modes with UCA. The following section will derive logistics cost functions per mode of transport, mainly using the papers mentioned above.

3.3 – Logistics cost function

This section will derive the logistics costs function or the calculations used for each mode of transport, the model for (unmanned) aircraft is mainly derived from the model of Hoeben (2014). Appendix 1 defines all the variables. Step by step the formulas will be explained for each mode of transport analysed, if necessary with elaborations in the appendix. One formula that implies for all modes is the frequency of transport, as the ideal mode of transport depends on the freight flow between destination A and B. In that matter all costs will be calculated per week, which is similar to the model of Hoeben. In that matter the costs made for one way per mode should be multiplied by the frequency. This frequency is dependent on the fright flow, and that must be divided over the shipment volume that fits in the mode of transport. This leads to the following expression:

$$f = \frac{q_{AB}}{Q} \qquad (1)$$

The formulas for all modes are split up in two parts, transport costs and cargo costs. The latter is the same for each mode and especially important for this case study as it includes depreciation and the inventory-time costs (costs of cargo during transport and storage) of the goods transported. Hence this formula is extensively explained in section 3.3.1.

3.3.1 – Cargo costs

For all modes of transport cargo costs of high value goods are of great importance to implement in the costs function, including the time costs of transport. Hence this is the part of the model taking into account the loss of value during transport. As Hoeben (2014) derived, this function comes down to:

$$C_{cargo} = C_{warehouse} + C_{inventory} + C_{handling} \qquad (2)$$

The warehousing costs are multiplied by a short formula with respect to time (t_{wait}). The 168 in the expression represents the number of hours in a week, dividing this by two times the frequency displays the mechanism of a shorter delivery time when the transport frequency per week increases. Assuming a uniform distribution with regards to cargo arrival times at the origin, the formula turns out as follows:

$$t_{wait} = \frac{168}{2 * f} \qquad (2a)$$

Goods that are waiting at the airport to be transported are stored in one of the warehouses, which come at a cost concerning the rent of the space, machinery needed to store in, and maintenance directly related to the provision of storage space, such as security (Hoeben, 2014). Herein especially the volume of the cargo matters in the rent costs (S), measured in $ per m^3. As in formula (1) q_{AB} is the weekly freight flow in kg and ρ is the density of the cargo in m^3/kg:

$$C_{warehouse} = S * \frac{q_{AB}}{\rho} * t_{wait} \tag{2b}$$

However, extra costs arise with respect to inventory costs. The flow time of the products in the supply chain is the time that elapses between the point at which material enters the supply chain to the point which it exits (Chopra & Meindl, 2016). Hence this includes the time at the warehouse and time during transit. These Inventory costs generally form the main reason to choose the relatively expensive form of air transport over other transport modes, as they represent the loss of opportunity and physical value of the goods during transit. These costs are particularly high for high-value goods, as analysed in this thesis.

Hoeben (2014) took devaluation arising from the loss of value due to quality decay of perishable goods over time. However with respect to high value goods such as electronics and automotive goods accounting for decay in quality is not necessary. The inventory costs of these goods in flow time are mainly due to costs arising from insurance, depreciation, obsolescence, and capital costs (loss of opportunity) (Burnson, 2011). On average the costs for high value goods are considerably higher than the interest rates alone (Thatcher, 2015) and are estimated to be 19% annually (Jones & Tuzel, 2009). The CSMPS logistics report indicates an even higher number of 22%, displaying the taxes, obsolescence, depreciation and insurance costs of all US business logistics costs related to inventory holding (Wilson, 2015). With only 10 states taxing inventory costs (Kaeding, 2016), some but not too much would be deducted from the 22%.

The standard rule for insurance costs at DHL is 10% over the sum of the product value and the transport costs. Therefore, also accounting for capital costs and devaluation, a 20% annual cost will be used for the high value goods, thus a rate of -0.0023% per hour (D_{rate}). Besides, due to uncertainty of the exact rate, a 15% rate will also be estimated, leading to a depreciation rate of -0.0017%. For accounting matters depreciation rates are usually determined monthly or yearly, as goods will not be transported for more than a month a linear depreciation rate will be incorporated. Capital costs, taxes, and devaluation are generally yearly (or monthly) percentages as well. Hence the exponential function of Hoeben (2014) is not necessary as this rate can be captured by a fixed rate per hour (his rate came down to 0.004 per hour). This rate depends on the value of the product and is calculated over the value of the cargo once it enters the supply chain.

$$C_{Inventory} = D_{rate} * V_{cargo} * \ Total\ transit\ time\ in\ hours \tag{2c}$$

In formula (2c) the constant V_{cargo} is the value of the weekly flow of the types of good when they enter the supply chain. The costs per hour depend on the value of the goods. The total transit time includes all time the goods are in the supply chain. Hence from the handling at the first warehouse, incorporating all time in transit or waiting time, to and including the handling at the final destination (warehouse).

The last part of the cargo function is concerning the handling costs. These costs include payments for unit loading device. Hence costs arise from packaging, loading and unloading. Therefore the handling costs are directly proportional to the cargo volume.

$$C_{Handling} = \left(\frac{q_{AB}}{\rho}\left(H_{\frac{load}{unload}} + H_{consilidation}\right) + Risk_{Damage}\right) * f \quad (2d)$$

Added to this formula, compared to the one used by Hoeben, are the risks of damage during handling time. However, even though this risk is mentioned in many books and articles concerning supply chain management, generally no percentage is given to it. To still estimate it, it is derived from the likelihood of bad handling equipment (assumed to create a high risk of damage) and the risk of crime, associated by theft. The costs of the (lost) goods are insured by the D_{rate} above, however this insurance does not cover the delay in time. Therefore the likelihoods of damage are multiplied by the number of hours delay they cause. It could however be that insurance costs are higher when goods switch modes more often, yet on the other side insurance costs could also be higher flying UCA. Yet only on the short term as insurance companies are not familiar with them yet and thus account for higher risks. Concerning the long term, when UCA have proven to be save, this rate will decrease. Due to insecurity about the actual higher or lower rates the current rate of DHL (10%) is the one used. Both $H_{load/unload}$ and $Risk_{Damage}$ depend on the number of transfers.

According to Vilko and Hallikas (2012) the likelihood of bad cargo handling equipment and crime in the supply chain is both 1 on a scale of 0,1,3,9 where 0 implies 0 likelihood and 9 implies very high likelihood (Vilko & Hallikas, 2012). Both the bad condition of cargo equipment and the crime have a likelihood of 0.00023, of which the former leads to a delay of most likely 1 day (24 hours) and the latter 0.5 day (12 hours). Realising that these measurements might not be exactly accurate, these come closest to a cost value approach of the risk of handling. Therefore the formula of $Risk_{Damage}$ is the risk multiplied by the costs when the damage occurs, thus the extra time costs of the good, all multiplied by the number of times the goods switch modes (M_s)

$$Risk_{Damage} = (0.00023 * D_{rate} * V_{cargo} * 24 + 0.00023 * D_{rate} * V_{cargo} * 12) * M_s \quad (2da)$$

This formula for cargo, derived as Hoeben (2014), yet with an exception of the inventory costs and risks of damage, is added to the transport costs of each of the transport modes. Adding all these together leads to the following function for cargo related costs:

$$C_{cargo} = S * \frac{q_{AB}}{\rho} * t_{wait} + D_{rate} * V_{cargo} * Total\ transit\ time\ in\ hours + \frac{q_{AB}}{\rho}\left(H_{\frac{load}{unload}} + H_{consilidation}\right) + Risk_{Damage} * f \quad (2e)$$

The transport functions will be derived in the next sections.

3.3.2 – Logistics cost function aircraft

The cost function for aircraft must entail airport rates, handling costs, risks of damage during handling, aircrew costs, fuel costs, aircraft depreciation costs, aircraft maintenance costs, and costs of cargo during transit and storage. Furthermore the environmental impact will be taken into account, however with currently no direct costs these will not be included in the formula, yet analysed separately in the discussion. The logistics cots function will consist of transport and cargo costs, of which the latter is derived in the previous section. The transport related costs for aircraft are depicted in this section, the costs are made up from the following formula:

$$C_{transport} = C_{airport\ usage} + C_{aircrew} + C_{fuel} + C_{A/C\ depreciation} + C_{maintenance} \quad (3)$$

The first variable contributing to the transport costs are the airport usage costs. These costs consist of the rate of the airport user charges, which include charges for landing and take-off, ground handling, security, and parking. These costs generally depend on the type and size of the aircraft, usually determined by its maximum take-off weight (MTOW). The airport rates and MTOW, of which the rates are retrieved from Schiphol via Hoeben (2014), will be multiplied by the frequency of the flights to end up with the weekly costs:

$$C_{airport\ usage} = R_{airport} * M_{MTOW} * f \quad (3a)$$

Concerning the costs for the aircrew, which are costs that will be eliminated for a great part when flying with UCA, are determined by the costs of the crew per block hour (A) times the number of hours the crew is at work. The per hour rates of the crew depend on the aircraft type and route distances, though also overtime pay, standby pay, allowances and sector pay are included in the rates used from Hoeben (2014), adjusted for inflation. Hence salary rates are based on western (European/American) rates. With respect to the unmanned aircraft, the salary rates will be, as Lugtig and Prent (2012) did, divided by the number of UCA remotely controlled at the same time. Hence divided by 12. Again, the costs will be multiplied by the frequency:

$$C_{aircrew} = A * T_{block} * f \quad (3b)$$

Fuel costs consist of a great part of the operating costs of an airline and can be calculated rather simple, by multiplying the aircraft fuel consumption by the price of the fuel. Keep in mind this is only accurate for long-haul flights, for short-haul flights the linear prediction between fuel consumption and distance is not accurately predictable (Hoeben, 2014). This fuel price will be deviated at part of the sensitivity analysis. Again, the formula is multiplied by the frequency:

$$C_{Fuel} = P_{fuel} * FC * f \quad (3c)$$

The aircraft depreciation costs are somewhat more difficult to determine, first of all the time span of the depreciation must be determined. Citing Hallerstrom:

> "The theoretical value of the aircraft is the net present value of all the future cash flows that can be generated from the operation of the aircraft. Although aircraft do not have a limited technical life, their economic life ends when a positive net cash flow can no longer be generated." (Hallerstrom, 2013, p. 26)

His definition is also used by Hoeben, hence to arrive at his expression for depreciation costs, the aircraft new value is multiplied by the daily depreciation rate (W). This rate is obtained by (Kelly, 2008), by means of conducting a regression analyses on a scatterplot of aircraft current market value (CMV) against aircraft age. The multiplication of the deprecation rate, the block time of a flight, the frequency, and the price of a new aircraft ($P_{A/C\ new}$) will be divided by the aircraft utilisation (U). Hence the aircraft utilisation determines the number of operational hours over which the depreciation costs are spread out:

$$C_{A/C\ depreciation} = W * \frac{T_{block} * f}{U} * P_{A/C\ new} \quad (3d)$$

The operational hours used per aircraft are linked to the schedules they operate on. As the UCA is independent of any schedule limitations this aircraft is assumed to fly 21 hours a day. The other three hours can be used for (un)loading, fuelling and maintenance. As elaborated in chapter four, the Boeing 777 and 727 are the other two aircraft analysed in this thesis. The former is assumed to fly 15 hours a day as this is the utilisation of the Boeing 747-400F of KLM between Amsterdam (fairly close to Frankfurt) and Hong-Kong (Hoeben, 2014). The Boeing 727 is also assumed to operate 15 hours a day as this is its flight time from Stuttgart to Hong Kong, for elaboration see chapter four.

To complete the costs function with respect to transport, the maintenance costs must be determined. Generally, the more flight hours an aircraft makes, the earlier the machine is in need for service. The total block hours flown are included in the expression for maintenance cost. Maintenance can be divided into engine and airframe maintenance, both require labour (lab) hours and materials (mat). Hence the formula for maintenance consist for 4 sections:

$$C_{Maintenance} = C_{lab,airframe} + C_{lab,engine} + C_{mat,airframe} + C_{mat,engine} \quad (3e)$$

Each of these sections depends on a maintainability matrix that covers the differences in aircraft type on per-hour maintenance costs, aircraft age, and engine maturity. With respect to labour, the rates (R_{labor}) used by Hoeben (2014) will be taken, as will the maintenance man-hours per block hour (MHR), adjusted for inflation. This results in:

$$C_{lab,airframe} = MHR_{airframe} * R_{labor} * T_{block} * \mathrm{f} \quad (3ea)$$

$$C_{lab,engine} = 1.3 * MHR_{engine} * R_{labor} * T_{block} * \mathrm{f} \quad (3eb)$$

Similarly to labour, the costs of maintenance materials are calculated from the maintenance materials cost per block hour maintainability metrics:

$$C_{mat,airframe} = MAT_{airframe} * T_{block} * \mathrm{f} \quad (3ec)$$

$$C_{mat,engine} = 1.3 * MAT_{engine} * T_{block} * \mathrm{f} \quad (3ed)$$

The 1.3 in the formulas above is included to incorporate the cycle dependent wear of engine-components.

Adding the functions for transport and cargo gives the following (simplified) expression:

$$C_{logistics} = C_{transport} + C_{cargo} \quad (4)$$

Filling in this expression (4) with all the derived formulas in section 3.3.1a and 3.3.1b the logistic costs function for manned and unmanned aircraft arises:

$$C_{logistics} = R_{airport} * M_{MTOW} * f + A * T_{block} * f + P_{fuel} * FC * f + W * \frac{T_{block} * f}{U} * P_{\frac{A}{C}new} \quad (4a)$$
$$+ (MHR_{airframe} * R_{labor} + 1.3 * MHR_{engine} * R_{labor} + MAT_{airframe} + 1.3 *)$$
$$+ MAT_{engine} * t_{block} * f + S * \frac{q_{AB}}{\rho} * t_{wait} + D_{rate} * V_{cargo}$$
$$* Total\ transit\ time\ in\ hours + \frac{q_{AB}}{\rho}\left(H_{\frac{load}{unload}} + H_{consilidation}\right) + Risk_{Damage} * f$$

Note that the last part of formula (4a) is measured in weeks and therefore this part does not need to be multiplied by the frequency f. Once more, this formula is exactly the formula derived by Hoeben (2014). The formula will be filled in in chapter 5. All the variables are listed in appendix 1. The next section will continue with the calculation for logistic costs with respect to transport by rail.

3.3.2 – Logistics cost function train

The cost function for train entails rail handling costs, risks of damage during handling, costs of cargo during transit and storage that are calculated similar to the costs of the aircraft. In addition the machinist costs, electricity costs, depreciation costs, and maintenance costs must be calculated for the part of the train used. The transport costs of the train can be calculated, in proportion to the part of the train used, with the help of the following formula:

$$C_{transport} = C_{rail\ usage} + C_{crew} + C_{electricity} + C_{train\ depreciation} + C_{maintenance} \quad \text{(n/a)}$$

However, several inputs to this function such as the types of wagons and the length of the train are large influencers on the transport costs. Yet these costs are difficult to determine, as are the costs for rail usage and handling. Therefore the estimation of costs per TEU per km will be used for the transport part of this formula: \$0.70 per TEU per km (Rastogi & Arvis, 2014). As the modern silk route is brought to life recently it might be possible that these costs decrease in the future, in that case a lower rate of \$0.60 is estimated.

Besides this amount, the cargo costs, which are costs that mainly arise with longing transport time, must still be estimated. The transit time currently is measured in days, as will be elaborated on in chapter 5, hence these days will be multiplied by 24 hours to be able use the same measures (block hours) as done in the function derived in section 3.3.1. As with the cargo costs for aircraft, this entails warehousing costs, inventory costs, and handling costs. Hence formula (2) can be used. The general logistics costs function for train thus comes down to:

$$C_{logistics} = nr\ of\ TEU * km * 0.70 * f + S * \frac{q_{AB}}{\rho} * t_{wait} + D_{rate} * V_{cargo} \quad (5)$$
$$* Total\ transit\ time\ in\ hours + \frac{q_{AB}}{\rho}\left(H_{\frac{load}{unload}} + H_{consilidation}\right) + Risk_{Damage} * f$$

3.3.3 – Logistics cost function ship

Shipping is the slowest yet cheapest form of transport. However when transporting goods that are highly time sensitive and that devaluate with every hour extra transported, this mode can still be more expensive than rail or aircraft due to the high inventory costs. Van Hassel et all (2016) analyse sea shipping costs incorporating all transport costs comparable to the ones incorporated for aircraft. Hence costs for crew, depreciation, maintenance, and the use of facilities. However, even though this model is very applicable to use, the shipping market currently operates under loses. Therefore shipping a container is cheaper than the costs made by the carrier. As a result an average of the rates on the spot market is chosen to serve as an indication. These rates (P_{spot}) depend on the route sailed and on the number of containers or whether a less than fully loaded container is transported. In chapter four a table will be presented indicating the rates for the route sailed. As these rates are very low the cargo part (inventory costs) is expected to comprise of a large part of the costs of sea shipping:

$$C_{logistics} = P_{spot} * nr\ of\ TEU + S * \frac{q_{AB}}{\rho} * t_{wait} + t_{wait} + D_{rate} * V_{cargo} * Total\ transit\ time\ in\ hours + \frac{q_{AB}}{\rho}\left(H_{\frac{load}{unload}} + H_{consilidation}\right) + Risk_{Damage} * f \quad (6)$$

3.3.4 – logistics cost function truck

Trucks are a very flexible and relatively cheap mode of transport over land. The formula for trucks include toll costs, costs for the driver, fuel costs, truck depreciation and maintenance costs. Hence the formula will be as follows:

$$C_{transport} = C_{toll} + C_{driver} + C_{fuel} + C_{depreciation} + C_{maintenance} \quad (7)$$

Toll costs can simply be added and be multiplied by the number of times the truck will drive this route:

$$C_{toll} = (toll_1 + \cdots + toll_n) * f \quad (7a)$$

With respect to time travelled, truck drivers need to rest every couple hours according to regulations. Sufficient hours of sleep need not to be incorporated in the transport and cargo costs functions as the trucking time will not exceed eight hours in this study. Yet concerning other rest hours, similar to Kremers (2012) this thesis assumes that the truck drives needs to rest for 45 minutes every 4.5 hour. In the transport function this is incorporated within the costs for the driver:

$$C_{driver} = \left(hourly\ wage * \frac{distance}{\max speed} + T_{rest}\right) * f \quad (7b)$$

Fuel is calculated exactly the same as the formula for aircraft, yet with different prices as trucks usually drive on diesel instead of jet oil. Average fuel rates for a Volvo truck is about 6 miles per gallon (Barnes & Langworthy, 2003). Thus:

$$C_{Fuel} = P_{fuel} * FC * f \quad (7c)$$

Maintenance costs include general maintenance, repair costs and tire costs, which are estimated to be 10.5 cents ($) per mile for the entire life of the vehicle (Barnes & Langworthy, 2003). These results are based on a literature review, yet this literature does not specify mileage-based depreciation costs separately (Barnes & Langworthy, 2003). However the paper concludes by use of a somewhat dated source and a recent interview with the head of a small trucking company and average of 8 cents per mile throughout the whole lifecycle of the truck (Barnes & Langworthy, 2003). \$0.105 per mile and \$0.80 per mile come down to respectively \$0.07 per km and \$0.50 per km[3].

Hence the formula for maintenance and depreciations costs can be:

$$C_{depreciation} = 0.50 * distance * f \tag{7d}$$

$$C_{maintenance} = 0.07 * distance * f \tag{7e}$$

With respect to cargo and the general logistics cost function formula (3) and (4) can again be applied. Thus the complete logistics costs function for trucks is:

$$C_{logistics} = (C_{toll} + hourly\ wage * \frac{distance}{\max speed} + T_{rest} + P_{fuel} * FC + 0.5 * distance + 0.07 * distance) * f + S * \frac{q_{AB}}{\rho} * t_{wait} + D_{rate} * V_{cargo} * Total\ transit\ time\ in\ hours + \frac{q_{AB}}{\rho}\left(H_{\frac{load}{unload}} + H_{consilidation}\right) + Risk_{Damage} * f \tag{8}$$

3.4 Concluding remarks

This chapter presented how the costs benefit analyses will be conducted. The modes of transport compared are unmanned aircraft, manned aircraft, train, ship and truck. As done in previous research they are compared in terms of costs and therefore all benefits and limitations are measured in monetary values (\$[4]). Costs measured are real costs of transporting the amount analysed, this means that when actually transporting goods, often different prices are demanded by forwarders or shipping companies. This is simply because of supply and demand, for instance in case of unbalanced trade flows (Pomfret & Sourdin, 2010). How this would impact the results will be elaborated on in the discussion.

[3] 1 km is 0.6214 miles, or 1 mile is 1.6093 km, thus 0.105 cents per mile is equal to 0.065 per km and 80 cents to 0.49 per km.

[4] Costs from € tot \$ have a fixed exchange rate of €1 = \$1.1148

Chapter 4 – Case study

UCA are expected to be beneficial transporting high-value cargo on long-haul (intercontinental) routes. Especially when a region is not directly connected (yet) by cargo or passenger airlines and flows by shipping, rail or road connections are slow, UCA can be cheaper when taking time depreciation costs of cargo into account. Therefore the costs of UCA will be compared to all modes of transport, incorporating these cargo depreciation costs. Hence two regions must be chosen to connect with a region on the other continent. This chapter indicates the case study and why it is considered beneficial for UCA in section 4.1. A complete market analyses can be found in attachment one and two. Section 4.2 depicts the characteristics and routes of the modes of transport considered.

4.1 Market analysis Europe – Asia

Regions not served by air cargo airlines yet that must currently export their long-haul products via other modes of transport or with several modes of transport in one chain, might save more than the two percent in costs calculated by the case study of Hoeben (2014). Asia and Europe are a good example of two continents, connected by both land and sea, and with a market comprising 31 percent of the world's long-haul cargo traffic and approximately 19.6 percent of the total world's air cargo traffic in tonne-kilometres. With an average annual growth rate of 5.5 percent between 1998 and 2013, growth on this trade route was slightly higher than the world average growth rate of 5.2 (Boeing, World Air Cargo Forecast 2014-2015, 2014).

About 2,130,000 tonnes is transported from Europe to Asia, consisting of mostly general industrial machinery (Boeing, World Air Cargo Forecast 2014-2015, 2014). Somewhat less though only 3 percent, 2,070,000 tonnes, flies the other way, mostly consisting of computers, electrical machinery and apparatus (Boeing, World Air Cargo Forecast 2014-2015, 2014). A figure and elaboration on the types of goods can be found in appendix 3. In line with the numbers of Boeing, the goods considered in this thesis are in the first place high-tech goods, in which China is the world's largest high-tech exporting country, producing 16.9 percent of global high-tech exports (Xing, 2014). Within Europe, Germany clearly is the largest player in terms of the high-technology sector, high-technology manufacturing and knowledge-intensive high-technology services. Secondly, the automotive industry (industrial machinery), is very strong in Germany, therefore representing the goods flying east.

UCA are technically able to fly to anywhere in the two mentioned countries. Though within the scope of this thesis only two routes will be analysed. For Germany this will be Stuttgart, that hosts many international technological companies with a focus on automobile technology and industrial technology, yet also computer technology (ORBIS, 2016). Examples of companies situated here are Robert Bosch GmbH, Vector Informatik GmbH, Hewlett Packard, Mercedes-Benz and Porsche. Geographically Stuttgart is broadly in the middle of Munich and Frankfurt am main, two large (cargo) hub airports. Especially Frankfurt, which is together with Schiphol Airport and Paris CDG of one largest airports in Europe (van de Voorde & de Wit, 2013). Feeding is an important phenomenon for these intercontinental hubs, of which a lot happens by trucking under the name of air transport (van de Voorde & de Wit, 2013). Hence concentrating on Stuttgart, cargo that now transfers at *at least* one hub airport, will be able to fly directly by UCA. From Stuttgart the routes to two different regions will be analysed.

To incorporate both a region connected by sea and one by land, two different cities in China are analysed. The first important criterion in which UCA are expected to operate beneficially points out that between this region and Stuttgart no direct air trade is currently existing, resulting in low demand numbers for air transport. In these situations UCA can offer a solution for cheaper yet fast transport than the modes currently existing in those regions. It can be expected though, that with the introduction of the relatively cheaper but fast mode of transport, the business in the region will strengthen and air cargo demand is growing. In this case UCA might be considered as a transition mode which operates between the regions as long as demand is small and will be taken over by larger aircraft (possibly unmanned in the future) when demand is sufficient.

However, before they start to operate, the region must have some demand or supply of high-value cargo, or at least an indication that this supply or demand might grow with the implementation of UCA. Consequently the first region analysed in the case study, with a sea harbour, is Shenzhen. Shenzhen is large city with a strong focus on high-tech and with a several high-tech companies situated there, such as Huawei, ZTE and Skyworth. Still air cargo mostly flies via Hong Kong which means extra handling time and more transfers imposing the risk of damage. Even on the route between Shenzhen and Frankfurt Am Main or Amsterdam, there are no direct flights and cargo flies indirectly with at least one transfer at Hong Kong. There is no direct rail connection. Interesting side note, Shenzhen also locates DJI, a large drone company, though these drones focus on photography.

Whereas Shenzhen is connected by a sea harbour, yet not by rail, the case for Urumqi is the other way around. Urumqi is connected by rail, though this landlocked city is not connected to a seaport nor directly linked to any region outside East-Asia by its airport, and will therefore complement this research with a case indicating the benefits that UCA can offer to developing regions that still need to make a transition towards the global world economy. Despite Urumqi not being directly connected to the western world by air, the city is along the rail network between Germany and Chongqing/Chengdu. Bedsides, some high tech industry can be found, with institutes as the Xinjiang Machinery Research Institute company Ltd or Urumqi Siruite Mechanical Equipment Co., Ltd. In addition the city is incorporated in the China Western Development strategy. That indicates that this region has potential and products to trade with the rest of the world, yet is in a less competitive position compared to other regions producing similar goods.

Concluding, Stuttgart hosts a number of companies focussing on high-tech machinery (automotive) or electronics. Hence this city is not directly connected to two of China's cities which are also active in these industries, Shenzhen or Urumqi. Therefore UCA could improve the trade position of these Chinese cities impressively, introducing a faster mode of transport than the ones currently existing, yet a cheaper mode than regular air cargo. However, the transitions that might be made with the implementation of the (possibly) cheaper UCA can be small or lager. Hence the effects on demand for air cargo by the implementation of UCA are very uncertain. The following sections give an indication on the amounts of cargo currently flying on this route and an overview of possible amounts in the future. Numbers are gathered by IATA by means of measuring how much cargo flies from A to B. Hence this tells nothing about the (de)route the cargo has flown. For this thesis the best available airfreight data comes from IATA statistics in 2010, retrieved by ORTEC Consulting.

4.1.1 - Stuttgart – Shenzhen

With machinery being such a large part of the Europe-Asia market (see appendix 3) Shenzhen is an interesting city to analyse. Machinery is often extremely high of value, time sensitive and large. Those characteristics indicate that the less handling (transfers) the better, both in terms of time and risks for damage. Shenzhen, part of the free trade zone, hosts for instance ASML and Brion Technologies Co. Ltd. The former produces large machinery for chips whereas the latter is a company that imports and sells these machines to the Chinese market. Whereas ASML is not situated in Stuttgart it does outsource work to a number of companies in Stuttgart (De Lange, 2016). A company that is situated in Stuttgart is (for instance) Mercedes, a brand of Daimler AG. Daimler AG, with headquarters in Stuttgart, and Mercedes are also situated in Shenzhen. Besides, the Shenzhen BYD Daimler New Technology Company is a joint venture between BYD Auto and Daimler situated in Shenzhen and focussing on electric cars.

Aside from the automotive industry, of which goods mostly fly west to east, Shenzhen also hosts companies producing high-tech electronics, such as Huawei, ZTE, Skyworth, and DTI. These goods generally fly from east to west. However, as mentioned earlier, cargo often flies a detour. Hence cargo between Stuttgart airport (STR) and Shenzhen airport (SZX) does not fly direct at all, as most cargo that flows between Stuttgart and Shenzhen goes indirectly via the hub airports Frankfurt and Hong Kong. That means that exact numbers on these flows are hard to gather, though an insight in the numbers is given in appendix 3. As elaborated on in this appendix, west-east had in 2010 an average market weight of about 5000 kilograms per month, whereas east west comes down to only 900 kilograms a month[5]. The former had an average price of $3.34 and the latter of $1.81 indicating that importing is more expensive in the developing country. Hence the flows on these routes, as between Shenzhen and Stuttgart, are often not balanced. In this case the big advantage of UCA is that they can make circle trips instead of roundtrips.

Before determining the averages on the routes and estimate the current and future demand for air cargo included in the calculations for UCA, it should be noted that both Stuttgart and Shenzhen are quite developed regions that are likely to trade more goods than the data above indicate. In the case of trucking under airport note the data would account for cargo moving from Stuttgart to the largest European cargo airport Frankfurt by truck or cargo moving from Hong Kong, the world largest cargo airport, to Shenzhen. However if companies truck the cargo to the airports themselves and only then hand it over to an airline, the cargo is not registered in this data. That indicates that the current connection directly by aircraft is not beneficial enough, yet that it is likely that more airfreight is flowing between these cities. Hence the estimated current averages of airfreight will be forecasted for the future using the predicted growth rate, yet also including a sensitivity analysis incorporating the extra flow of goods by air when this option becomes relatively cheaper.

The averages of the routes between Stuttgart and Shenzhen can be estimated for 2016 by multiplying the 2010 data by the average growth rate of 5.5% per year for the past few years (see section 1 of this chapter). These numbers are depicted in the first two rows of table 1. However, the implementation of UCA is impossible to occur in within this year, 2016. Therefore some forecasting must be done to

[5] When excluding the zero data months, see attachment two for an explanation.

estimate the quantities shipped by air in the future, until this point not incorporating any effects of UCA. These numbers are depicted in table 1, row 3 and 4, below:

Estimated current and future average market weight of air cargo per week, without UCA				
Route	2009-2010	2016*	2020**	2025**
STR – SZX	1167 kg	1609 kg	1911 kg	2370 kg
SZX – STR	210 kg	290 kg	344 kg	427 kg

* Estimated by the earlier mentioned growth rate (5.5%) along these (6) years: 1.055^6 * average market weight 2009-2010.
** Estimated by the predicted growth rate of 4.4% per year (expected until 2033)
Table 1: Estimated current and future average market weight. Source: IATA, only for 2009-2010

However, as UCA can be expected to be a cheaper and attractive alternative to other modes of transport, effects of more demand for air cargo should be included. However, it is very unclear what the magnitude of these effects will be. Due to this uncertainty a sensitivity analysis will be conducted with respect to demand. Hence table 2 below gives the expected average market weight for 2020 and 2025, in line with the average growth of 4.4% per year plus the effects of a weekly demand 1.5 times or twice as large due to the implementation of UCA. The analysis will include all demand scenarios.

Estimated future average market weight of air cargo per week, with effects UCA				
Route	2020: 50% increase	2020: 100% increase	2025: 50% increase	2025: 100% increase
STR – SZX	2867 kg	3822 kg	3555 kg	4740 kg
SZX – STR	516 kg	688 kg	641 kg	854 kg

% increase with respect to the value of the same year in table 1
Table 2: Estimated current and future average market weight. Source: IATA, only for 2009-2010

It can be concluded from the air cargo analysis between Stuttgart and Shenzhen, both directions, that demand for direct airfreight seems to be small and unstable. Comparing the directions it became visible that more goods flow from Stuttgart to Shenzhen than the other way around. The small and unstable demand does not mean that all other goods are shipped over the ocean instead of by air, goods are likely to fly via Frankfurt or Hong Kong and are trucked to and from these major airports. Taking that together indicates that it is likely that more demand exists than the numbers shown in the tables, yet that direct air transport is not attractive enough to be widely used. This is likely to lead to a boost in airfreight demand if UCA can prove to be a cheaper mode of transport. Tables 1 and 2 indicate estimates of possible boosts in demand. However, as these numbers on airfreight flows are very uncertain and crudely estimated, a sensitivity analysis will be conducted to see the effect of different fright flows. For this route the comparison will be made with air, shipping, and trucking. The next section will depict demand for the city along the modern silk line railway instead of a harbour, Urumqi.

4.1.2 - Stuttgart – Urumqi

Landlocked Urumqi has due to its geographical characteristics no possibility to transport via the cheap option of shipping. Though since 2015, the improved Yu'Xin'Ou railway, better known as the modern silk route, is connecting Urumqi and other Chinese cities such as Chongqing, Chengdu, Xian and Lanzhou to Duisburg, Germany. Section 4.2.3 will elaborate on the duration and characteristics of this rail track. Besides rail, cargo currently flies via for instance Shanghai or Beijing, hence a direct flight between Urumqi and anywhere outside Asia is currently not operating. The average cargo flows of 2010 are analysed in appendix three and indicate an average for of 228 kilograms per month at an average price of $5.08, the other way around seems to have no air cargo demand.

As explained in the previous section, on top of the estimations of expected future demand with demand growing along with the worldwide trends, a sensitivity analysis will be conducted to include the possible effects of the implementations of UCA in 2020 and 2025. All demand scenarios are depicted in table 3 and 4 below. However, currently there seems to be no cargo flowing between Urumqi and Stuttgart. UCA could in this case simply fly from Stuttgart to Urumqi and after that on to a region that does demand goods from Urumqi and supply for Stuttgart and in that case make a 'circle' trip. However it is also possible that demand arises as a cheaper yet fast mode arises with the introduction of UCA, for that matter future demand is simply set at 50 kg per week from 2020 onwards. Hence it should be realised that this number is randomly chosen.

Estimated current and future average market weight of air cargo per week, without UCA				
Route	2009-2010	2016*	2020**	2025**
STR – URC	85 kg	118 kg	133 kg	173 kg
URC – STR	-	-	-	-

* Estimated by the earlier mentioned growth rate (5.5%) along these (6) years: 1.055^6 * average market weight 2009-2010.
** Estimated by the predicted growth rate of 4.4% per year (expected until 2033)
Table 3: Estimated current and future average market weight. Source: IATA, only for 2009-2010

Estimated future average market weight of air cargo per week, with effects UCA				
Route	2020: 50% increase	2020: 100% increase	2025: 50% increase	2025: 100% increase
STR – URC	209 kg	266 kg	259 kg	346 kg
URC – STR	50 kg*	100 kg*	75 kg**	200 kg**

% increase with respect to the value in the same year in table 3
* Increase of 50 kg / Increase of 100 kg, **50% increase with respect to 50 or 100 kg
Table 4: Estimated current and future average market weight. Source: IATA, only for 2009-2010

It can be concluded that, at least concerning air freight demand, currently very little and unstable demand is flowing on the market between Stuttgart and Urumqi. Urumqi only seems to import cargo and thus not export at all by air, as there is no cargo flying the other way around. When looking at similar cities to Urumqi, such as Lanzhou, the same phenomenon holds. Little cargo flies from Stuttgart to Lanzhou, nothing the other way around. This is understandable as the prices seem to get pretty high on this route (see appendix three). Compared to the previous analysed route, Stuttgart - Shenzhen, cargo flows are even more unstable and a similar trend seems that demand is higher for Stuttgart-China than the other way around. That, as said in the literature, leads to higher prices to export (from China).

4.2 – Modes of transport

As mentioned before, all possible modes of transport will be analysed in comparison with UCA. This section will picture the current available modes and consequently the ones analysed in this thesis. In order to clarify to which UCA these modes will be compared, this is the first mode of transport to be defined, including characteristics and transport routes for the case study between Stuttgart – Shenzhen and Stuttgart – Urumqi. After which the characteristics of the other modes, manned aircraft, rail, shipping, truck (including intermodal) transport will be defined in terms of capacity and travel time. The possibilities for freight flows between the regions will be indicated by figures that include symbols of the mode of transport, which will all explain their selves visually. The section will conclude with a graph indicating which modes and their respective time and capacity will be analysed. The unloading at the final destination (warehouses), assumed to be the same for all, will take half an hour for both truck and UCA. Flight distances are retrieved from great circle mapper (Mapper, 2016) and Kilometerafstanden.nl (Kilometerafstanden.nl, 2016). The trucking distances for all scenarios are retrieved from google maps, with an exception for Hong Kong- Shenzhen, which is retrieved from Baidu (Chinese map).

4.2.1 UCA

The type of UCA analysed in this paper is operating under all the advantages mentioned in chapter 2, yet the specific characteristics in this case are not yet defined. Important to emphasize (once more) is that the UCA is not built not operating yet. Hence most characteristics can be defined as such that they are beneficial for this case study, as the UCA would have to be designed either way. Consequently, with respect to size, the UCA can carry 5 tons of payload. The cruising speed of this relatively small aircraft is between 400 and 500 kilometres an hour (250/300 miles per hour) at an altitude of six kilometres (20.000 feet). In terms of size the UCA is similar to the Fokker F27-200, yet the airframe is assumed to be 20% more lightweight. In reality the UCA would probably have a different aerodynamic shape. Appendix 2 elaborates on the comparison to the F27-200

Characteristics and Costs UCA	
List price	$ 5,625,000
Remoting pilot ($59/12)	$4.92/h
Range at payload	10,000 km
Max payload*	5 tons
Operating Empty Weight	8.2 tons
MTOW*	30 tons
Maintenance:	$590/h
- MHR Airframe	3.8 h
- MHR engine	0.3 h
- MAT Airframe / block hour	$ 101.74
- MAT engine / block hour	$ 62.71
Cruising speed:	450 km/h
(Un)loading/handling time	0.5h
Turnaround time	1h

*Max payload at assumed range.

Table 5 – Characteristics and Costs UCA

At the altitude the UCA would be flying it is efficient to fly with a turboprop engine. In line with Hoeben, the aircraft characteristics of engines are similar to those of current commercial aircraft as there are no reasons at a technical level that these aircraft could not be operated without a pilot (Hoeben, 2014). With the aircraft specifically designed for unmanned operations structural changes with respect to aero dynamic form and the simplified light-weight construction can lead to a design of 20% less weight (Hoeben, 2014), leading to lower fuel usage. This combined with the turboprop engines can achieve a range of 1000-10.000 km (PUCA, 2016), assuming 10.000 in this thesis as the optimal form. However, a ground station is necessary to supervise the unmanned aircraft and take over in case of emergency, by steering it to the nearest airport (Hoeben, 2014). As Hoeben did, only the operational costs of the UCA and with that the ground station will be considered. That means only taking into account the salary of the operator, who can control up to 12 vehicles simultaneously (Cummings & Guerlain, 2007). Hence the UCA controller is in this case acting mostly as an air traffic controller, thus one twelfth of this will be the salary incorporated in the model. Yet the first and last half hour of the flight might be more of a pilot task, for this hour a pilot salary will be included.

Stuttgart – Shenzhen

Stuttgart 0h30' | *9175 km 20h23'* | *Shenzhen 0h30'*

Total time: 21h23'

Stuttgart – Urumqi

Stuttgart 0h30' | *5795 km 12h53'* | *Urumqi 0h30'*

Total time: 13h53'

The UCA will land and take off at industrial parks in Stuttgart, Shenzhen and Urumqi. The area considered for Stuttgart includes the industrial terrain around Daimler AG. In Shenzhen the Hi-tech Industrial Park is chosen, whereas for Urumqi it is the Hi-Tech Industry Development Zone (15 km) in Urumqi. All cargo handling and refuelling can happen at these terrains.

4.2.2 Aircraft

It is not a surprise that almost three quarters, 72 percent, of all air cargo moves by full freighter given the advantages for cargo that come with these aircraft (Boeing, World Air Cargo Forecast 2014-2015, 2014). Full-freighters offer more predictable and reliable volumes and schedules, greater control over timing and routing, and a variety of service for outsize cargo, hazardous materials, and other types of cargo that cannot be accommodated in passenger airplanes (Boeing, World Air Cargo Forecast 2014-2015, 2014). However, as mentioned before, the amount of cargo that is transported in a full-freighter is significantly higher than in passenger flights, requiring sufficient demand to operate profitable. According to Boeing (2014) it takes about 150 daily passenger flights to provide equal service to 10 daily full-freighter flights. Medium-wide bodies are, as mentioned before, the most popular full-freighter models, carrying between 40 and 80 tonnes of cargo.

Characteristics and Costs Boeing 727-200F	
List price	$ 9.6 million
Airport Usage	$ 22
Salary very long haul**	$925/h
Range at payload	4400 km
Max payload*	10 ton
Operating Empty Weight	39 ton
MTOW*	265 ton
Maintenance:	$ 2739
- MHR Airframe	8.7
- MHR engine	2.7
- MAT Airframe / block hour	114
- MAT engine / block hour	521
Cruising speed:	917 km/h
(Un)loading/handling time	0.5h
Turnaround time	1h

*Max payload/MTOW are for the range mentioned.
** Very long haul: >12 hours

Characteristics and Costs Boeing 777-200F	
List price	$ 300 million
Airport Usage	$ 22
Salary long haul**	$958/h
Range at payload	9321 km
Max payload*	58 ton
Operating Empty Weight	129 ton
MTOW*	117 ton
Maintenance:	$ 1158
- MHR Airframe	22
- MHR engine	1.8
- MAT Airframe / block hour	918
- MAT engine / block hour	839
Cruising speed:	950 km/h
(Un)loading/handling time	0.5h
Turnaround time	3h

*Max payload/MTOW are for the range mentioned
** Long haul salary (8-12hours)

Table 6 – Characteristics and Costs Boeing 727 and 777

For a the comparison with the UCA flying to regions with little demand, an aircraft with a similar payload should be taken into account. From the available information for this thesis, the Boeing 727-200 is most applicable to this situation, however realising that this type is currently outdated. The max pay load of this aircraft used in this thesis is 10 tonnes, which leads to range of 4400 kilometres, a little less than 2750 miles (Boeing, 727-100/-200 Freighter General Arrangement, 2007). That is enough to fly to Urumqi with one stop, yet Shenzhen needs two stops. With this payload, this Boeing is similar to the payload of the UCA analysed.

The Boeing 727 must, as mentioned, make two extra stops to refuel when flying from Stuttgart to Shenzhen. As this is quite time inefficient another possibility is analysed for this case. It seems clear from that quite a lot of cargo flies via Frankfurt am Main in Germany and via Hong Kong in China, and that in terms of demand a wide-body full-freighter, the Boeing 777-200, with a maximum payload of 58 tonnes, can be filled in a week. A great advantage of this aircraft on this route is that it can fly fast and in one go between Frankfurt and Hong Kong. Therefore the option of cargo trucking from Stuttgart to Frankfurt and then flying to Hong Kong and trucking to Shenzhen is also analysed. Costs of the large aircraft will be in terms of the share used. The characteristics of the aircraft are depicted in table 6.

The figures below indicate the routes the cargo can fly when the main mode of transport is in one of the aircraft mentioned above. The Boeing 727-200F cannot fly directly from Stuttgart to Shenzhen nor Urumqi due to its range. Two stops must be made on the route towards Shenzhen, which is more than 9000 km. Without flying too much out of the fastest route, the first landing can be made in Kazakhstan, for instance Atyrau Airport (GUW). Then, coincidently Urumqi (URC) is situated best for the next stop. Hence, the route towards Urumqi will have the same stopover at Atyrau as the route to Shenzhen.

The routes are shown in the figures below. The Boeing 777 flies directly from Frankfurt am Main to Hong Kong, the cargo is then trucked to and from these airports.

The area considered for Stuttgart it includes the industrial terrain around Daimler AG to the airport in either Stuttgart or Frankfurt. In Shenzhen trucking is either from the airport of Shenzhen (22 km) or the airport of Hong Kong to the Hi-tech industrial park (56 km) In Urumqi it is from the airport to the Hi-Tech Industry Development Zone (15 km, no toll) in Urumqi. Trucking times are retrieved from Routenet (2016), incorporating the trucking routes and maximum speeds & toll fees. For china, the trucking times are calculated assuming an average speed of 70 km/h. The turnaround times indicated here are the shortest possible, however often these depend on the schedule of flights and can take 8 hours. Hence the most optimistic scenario is depicted below. A less optimistic schedule will be analysed as well, increasing the idle time at airports with 5 hours for the Boeing 777. Yet the times given are solely handling and transport times, excluding extra times spend at a warehouse or airport.

Stuttgart - Shenzhen, Medium Wide body (Boeing 727)

Stuttgart	*17 km*	*STR*	*3148 km*	*GUW*	*2784 km*	*URC*	*3375 km*	*SZX*	*22 km*	*Shenzhen*
0h30’	*0h27’*	*1h*	*3h26’*	*1h*	*3h02’*	*1h*	*3h41’*	*1h*	*0h32’*	*0h30’*

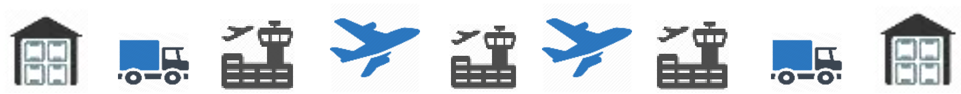
Toll: $0.61
Total time: 16h08’

Stuttgart - Shenzhen, Wide body (Boeing 777)

Stuttgart	*195 km*	*FRA*	*9171 km*	*HKG*	*56 km*	*Shenzhen*
0h30’	*2h40’*	*3h*	*9h39’*	*3h*	*1h05’*	*0h30’*

Toll: $27.41
Total time: 20h24’

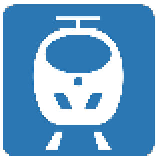
Stuttgart - Urumqi, Medium Wide body (Boeing 727)



Stuttgart	*17 km*	*STR*	*3148 km*	*GUW*	*2784 km*	*URC*	*15 km*	*Urumqi*
0h30’	*0h27’*	*1h*	*3h26’*	*1h*	*3h02’*	*1h*	*0h18’*	*0h30’*

Toll: $0.77
Total time: 11h13’

4.2.3 Rail



Rail is a (long-haul) mode of transport that is with respect to costs and speed in the middle of air and ocean (Rastogi & Arvis, 2014). The rail network between Germany and China connects the two powerful countries via the continent they share. Transporting along the modern Silk route, connecting Chongqing and Duisburg, takes cargo 17 days (Pieffers, 2016). Traveling from Duisburg to the first stop in China, has one arriving in Urumqi. As Chongqing is about 3000 km further, it can be assumed that a trip from Duisburg to Urumqi will take about 13 days. Included in this travel time is the transferring of cargo between rails as a result of incompatible rail gauges between China - Russia and Russia – Europe.

The types of goods transported are mainly electronics from East to West and automotive goods West to East. Currently more loaded freight trains move from China to Europe (about three times a week) than from Europe to China (about one time a week), which leads to empty trains going back to China (Rastogi & Arvis, 2014). However, aside from the trains operated by HP, who use all capacity for themselves, the trains do not (yet) have clear schedules (EVO, 2016). Hence a train operates when demand is sufficient, which makes the times very unstable. Concerning the handling facilities companies such as HP are trying to improve these as they currently cannot handle 45 feet containers yet. With these investments it can be expected that the trains will go on a more stable rate in the near future. Besides, the travel time is expected to decrease eventually to 10 - 11 days (Pieffers, 2016), yet an exact time span is not given.

With respect to this case study, the current time span will take into account the 13 day with trains transporting between Europe and China. The best available estimation of the costs for cargo to move on this railway is $0.70 per TEU per km (Rastogi & Arvis, 2014). Hence this is the amount used for the costs calculation. However, as the Chongqing-Xinjiang-Duisburg railway opened in 2011 (Szczudlik-Tatar, 2013) it can be possible that with growing interests and fewer empty trains going back to China the costs will lower. Therefore the costs of $0.60 per TEU per km will also be taken into account.

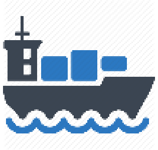
The cargo related costs are added to the estimations of transport costs of this railway, as explained in chapter 3. For Shenzhen the option by rail is not relevant to analyse. The new silk line only goes up to Chongqing and with the extra transfers from there to Shenzhen, shipping is about as fast as by rail. With shipping being cheaper than rail it does not make sense to transport via this route. Urumqi *is* along the Silk line, which makes the train possibly an interesting mode of transport for transport to Germany. Something similar is currently done by HP, ACE and Asus, from Chongqing, China to Duisburg (Rheinausen), Germany. On this route is Urumqi the first stop in China from Europe.

Stuttgart – Urumqi

Stuttgart	*422 km*	*Duisburg*	*7007 km*	*Urumqi*	*2km*	*Urumqi*
0h30'	*5h41*	*0h40'*	*312h*	*0h40*	*0h02'*	*0h30'*

Toll: $60.72
Total time: 320h03' (13 days 8 hours and 3 min)

4.2.4. Shipping



The last possible mode of transport analysed is shipping. Most Eurasian trade goes through the Suez Canal (Rastogi & Arvis, 2014), in 2012 the throughput was 40 million 20 foot equivalent units (TEU). Even though the rail link is gaining interest, this route cannot take over the throughput carried by sea completely, the potential throughput on the modern silk line is only one to two percent of what is currently carried by sea (Rastogi & Arvis, 2014). With respect to shipping several possibilities arise in terms of the transport over the ocean and inland shipping. Concerning inland transport, only the trucking from the port to either Stuttgart or Shenzhen is taken into account. Hence the differences in costs resulting from a change of port or change the mode of inland transport to barge or rail is left out of consideration. With Stuttgart being situated in the hinterland of Rotterdam this port will be considered. Information about turnaround times and costs for the terminals of the port of Rotterdam are available through the paper of van Hassel et al. (2016).

As mentioned in section 3.3.3, the prices paid for sea shipping are currently lower than the costs made by the carriers. Hence for a fair picture the average rates of the spot market are used for these calculations. Tables 7 and 8 give an overview of the rates per TEU (Twenty foot equivalent) or per CBM in case of a less than container load (LCL). March 2016 showed an all-time low of $211 per TEU on the Shanghai – Rotterdam route, which was $313 per FEU (Forty foot equivalent), hence it is assumed that the costs per FEU are 1.5 times the costs per TEU. Especially on the sport market, rates are difficult to determine. However, as the rates are currently very low, lower than the costs for the carrier, it is assumed that they will rise again in the future.

A less than container load (LCL) is relatively more expensive than a full container load. In case of a LCL the shipper does not need to take care of returning the container, hence the carrier has more work to this. Therefore the direct costs paid for a LCL are relatively higher than per TEU. According to Cargo from China (2016), rates are 2 to 3 times as much per cubic meter. This includes extra port services charges at the origin and destination port. As well, LCL containers take longer to process as it needs to be consolidated first, adding another day in time (Cargo from China, 2016). The costs are retrieved from the world container freight rate index and are the average costs for 2016[6]

Shipping rates: Shenzhen – Rotterdam	**Current (2016)**	**2020**	**2025**
Per TEU	$ 1000	$ 1250	$ 1500
LCL per CBM*	$ 53	$ 66	$ 79

* (Price per TEU/38 CBM)*2
Table 7

Shipping rates: Rotterdam - Shenzhen	**Current (2016)**	**2020**	**2025**
Per TEU	$ 625	$ 780	$ 975
Less than TEU	$ 33	$ 41	$ 51

* (Price per TEU/38 CBM)*2
Table 8

[6] Averages of Jan-Nov, December is forecasted, based on shanghai Rotterdam, Rotterdam shanghai

Shipping containers between Rotterdam and Shenzhen is estimated to take 26 days, sailing at a speed of 17 knots. Contrary to the train section, in this case Urumqi is not feasible to analyse, as the closest sea port is almost 3000 kilometres away. The following route for Shenzhen is taken into account:

Stuttgart - Shenzhen:

Stuttgart	*601 km*	*Rotterdam*	*18065 km*	*Shenzhen*	*42 km*	*Shenzhen*
0h30'	*7h52'*	*12h*	*26 days*	*12h*	*0h54'*	*0h30'*

Toll: $63.78
Total time LCL: 657h46' 27 days and 9h46'

4.2.5 Trucking

Trucking is not a mode of transport between Germany and China, yet it is part of the transport networks of aircraft, train, and ship. Hence the assumptions made for trucking must be clarified. Whereas for the Boeing 777, rail, and shipping the costs are only calculated per proportion of the mode used, this is not the case for trucking. Reasons for this are simplification and due to the fact that the truck mostly operates on a relatively small distance from sea- or air-port or train station to the supplier. If the truck would transport and deliver more goods than the goods considered per route, more time (waiting, transport) and kilometres should be added to the trucking time and distance. However determining this extra routing and time is out of scope in this thesis. Besides that the extra costs, mainly for the time, are now eliminated. That said it must be noted that especially for the case of shipping the trucking costs could turn out to be lower if goods move with a full truck load to Venlo and change to a smaller truck there, even if this takes extra time. Characteristics of the trucks are given in section 3.3.4., wages of truck drivers are assumed to be $36.88 per hour (German Salary Survey, 2016). Diesel price is $1.17 per litre.

4.3 Concluding remarks

Table 9 gives an overview of the distances and times travelled per mode of transport. So far it is clear that shipping is by far the slowest form of transport, after that the train takes a considerable amount of time. Comparing UCA to manned aircraft indicates a longer travel time if all time slots for the manned aircraft are ideally connected. When the idle time at an airport increases by one hour for the Boeing 777 or five hours for the 727, transporting by UCA becomes the fastest option. Until this point the ideal situations for all modes are depicted, however in the model costs will be calculated per week depending on different freight volumes and departure times of transport modes. Yet this information concerning transport times in ideal situations is still important for calculating insurances and risks during transit, as well as costs of goods stored in warehouses and costs of capital over the whole time span. Besides different time spans, several sensitivity analyses will be performed concerning the different fuel prices given in this chapter and inventory-time costs will be calculated at a rate of 15 and of 20 percent.

Mode(s) of transport	Stuttgart-Shenzhen Time	Stuttgart-Shenzhen Distance	Stuttgart-Urumqi Time	Stuttgart-Urumqi Distance
	21h23’	9175 km	14h53’	5795 km
 ***Boeing 727***	16h08’	Truck: 17 km Aircraft: 9307 km Truck: 22	11h13’	Truck: 17 km Aircraft: 5932 km Truck: 15 km
 ***Boeing 777***	20h24’ *or* 30h24’	Truck: 195 km Aircraft: 9307 km Truck: 56	n/a	n/a
	n/a	n/a	320h03’	Truck: 422 km Train: 7007 km Truck: 2 km
	633h46’ *or* 657h46’	Truck: 601 km Ship: 18065 km Truck: 42 km	n/a	n/a

Table 9 – Modes of transport with corresponding travel times

Chapter 5 – Value analysis

The previous chapters presented the information that will be used for the value analysis. As well, due to uncertainties for the future situations or other assumptions that are not definite, calculations are made with different values for fuel, freight flow, inventory time costs, and scheduling effects. Several modes of transport (UCA, manned aircraft, rail, truck and sea shipping) are considered and the calculations are made for either high-tech electronics (laptops, $600 each) from Stuttgart to Shenzhen or Urumqi and automotive (high quality turbo chargers, $1000 each) from Urumqi or Shenzhen to Stuttgart. All costs are calculated per week, meaning that when cargo is waiting at the origin warehouse to be shipped, inventory costs are accumulating.

Section 5.1 will introduce a base case presenting the ideal demand situation for UCA to which it is easy to compare the other scenarios, whereas section 5.2 will elaborate on existing and expected future demand rates. Future demand rates incorporate the changes in prices for rail and sea shipping. Section 5.1 will start with a subsection of the base-case scenarios, hence assuming the standard fuel rates, optimal schedules and standard inventory time costs, at demand of 5 tons a week. After this, a subsection for each of the just mentioned effects is presented: first taking into account different values for fuel (5.1.2), second the effects of transit times and schedules (5.1.3), and third an indication of consequences of time inventory costs (5.1.4). Section 5.2, incorporating the current and future demand will elaborate further on scheduling effects, as different demand rates affect schedules. Section 5.3 will depict a scenario of a manned aircraft as similar as possible to the UCA considered, hence the ideal situation for manned aircraft versus UCA. Section 5.4 will elaborate on sustainability and finally section 5.5 concludes with the main results of relevant scenarios.

The complete tables with results of the base cases will be shown in section 5.1.1, however due to the numerous tables the other sections only depict the relevant outcomes for either only transport, only cargo, or only total costs per good. The other outcomes can be found in appendix 4.

5.1 – Base case – Ideal demand situation UCA

With UCA having a capacity of 5 tons, the ideal situation would be market demand that is exactly this amount (in terms of weight). This section indicates the results of demand being exactly 5 tons per week, hence making it easy to depict the general feasibility of UCA and present a base case to compare the results of the current and future demand rates of this case study with. Whereas the latter will be done in section 5.2, this section will compare the base case to the effects of different fuel prices, scheduling and transit time, and inventory time costs.

5.1.1 Base-case

The standard case means a fuel rate of $1.50 per gallon jet oil, optimal schedule effects (no idle time at airports) and a yearly time inventory rate of 20%. The results are presented in the table 10 and 11 on the next page:

Stuttgart – Shenzhen: Automotive, Fuel $1.5/gallon, 5 ton freight, 735 turbo chargers, per unit $1000											
	Transport: excl. truck	**Total truck**	**Total Transport**	**Per Turbo**	**Total warehouse**	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Turbo**	**Total**	**Per Turbo**
UCA	$9,976.41		$9,976.41	**$13.57**	$2,087.63	$358.97	$1,254.26	$3,700.87	**$5.03**	$13,677.27	**$18.60**
777	$6,897.19	$390.56	$7287.75	**$ 9.91**	$2,087.63	$342.47	$6,231.29	$8,661.39	**$11.78**	$15,949.14	**$21.69**
727	$20,674.64	$37.00	$20,711.64	**$28.17**	$4,175.27	$270.84	$1,868.80	$6,314.91	**$8.59**	$27,026.55	**$36.76**
Ship	$612.24	$953.81	$1566.05	**$ 2.13**	$2,087.63	$11,042.28	$3,742.77	$16,872.69	**$22.95**	$18,438.74	**$25.08**

Table 10: Base case, Stuttgart - Shenzhen

Stuttgart – Urumqi: Automotive, Fuel $1.5/gallon, 5 ton freight, 735 turbo chargers, per unit $1000											
	Transport: excl. truck	**Total truck**	**Total Transport**	**Per Turbo**	**Total warehouse**	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Turbo**	**Total**	**Per Turbo**
UCA	$6,067.93		$6,067.93	**$8.25**	$2,087.63	$249.85	$1,254.26	$3,591.75	**$4.88**	$9,659.68	**$13.14**
727	$13,427.63	$27.83	$13,506.65	**$18.30**	$4,175.27	$189.70	$1,868.80	$6,233.77	**$8.48**	$19.740.42	**$26.85**
Rail	$6,520.76	$868.86	$7389.62	**$10.05**	$2,087.63	$5,372.85	$3,742.77	$11,203.26	**$15.24**	$18,592.88	**$25.29**

Table 11: Base case, Stuttgart - Urumqi

In the tables above the results can be seen when weekly demand is exactly that of the capacity of a UCA. For this scenario, looking at the total costs, UCA prove to be cheaper than all other modes on both routes. When looking at the transport costs only, the Boeing 777 turns out to be cheaper on route to Shenzhen, however note that the costs of the 777 are only calculated for the proportion of the aircraft used. The total costs of operations of the whole aircraft would be more than ten times higher. Lower transport costs for the share used of the Boeing 777 than for operating the UCA seem rational as the Boeing 777 and UCA both travel once a week, yet the wide body aircraft has a great scale advantage. The latter also partly explains the low transport costs compared to the Boeing 727. Furthermore, concerning only transport costs one can see that transport costs for only rail are in the middle of the UCA and the more expensive Boeing 727. Sea shipping comes at much lower costs than any mode by air and is by far the cheapest mode of transport. However when looking at the total cargo costs, especially the inventory costs during transit, sea shipping becomes more expensive than both UCA and the Boeing 777. The latter also becomes more expensive than UCA due to the total cargo costs, however in this case the largest share is caused by handling instead of inventory.

Handling costs comprise of loading and unloading costs, consolidation and the risks during handling. These are naturally higher for the Boeing 777, sea shipping, and rail due to the extra consolidation and handling at (air)ports. The handling costs are lowest for the UCA as goods do not transfer nor spend idle time at airports. Neither does the Boeing 727, yet its higher handling costs compared to UCA arise as the Boeing 727 has additional handling as goods are trucked to the airport. Concerning the warehousing costs the costs for the Boeing 727 are twice as high as the other costs, this occurs due to the frequency of transport. The Boeing 727 has a capacity of 10 tons and therefore flies only once every two weeks, thus 0.5 times a week, which make warehousing costs twice as expensive. Other remarkable numbers concerning transport costs are the big differences in trucking costs. These can be explained through the fact that trucking for the Boeing 777 goes to Frankfurt am Main, for sea shipping to the port of Rotterdam, and for rail to Duisburg. These distances are all quite far compared to the distance between the distribution centre in Stuttgart and the airport of Stuttgart.

In general total costs of transport and cargo are much higher for the Boeing 727 compared to the other aircraft or shipping, whereas rail is in this scenario only slightly less expensive. The differences in costs are especially large between the Boeing 727 and UCA, as they are almost twice as much. Chapter 6 will discuss this outcome further. Tables 12 and 13 below indicate the costs if instead of automotive goods, laptops would be transported in the other direction:

Shenzhen – Stuttgart: Laptop, Fuel $1.5/gallon, 5 ton freight, 1706 Laptops, per unit $600

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$9,976.41		$9,976.41	**$5.85**	$2,983.27	$499.87	$2,054.61	$5,537.74	**$3.25**	$15,514.15	**$9.09**
777	$6,897.19	$390.56	$7287.75	**$4.27**	$2,983.27	$476.88	$9,383.52	$12,843.67	**$7.53**	$20,131.42	**$11.80**
727	$20,674.64	$37.00	$20,711.64	**$12.14**	$5,966.53	$377.14	$2,811.63	$9,155.31	**$5.37**	$29,866.95	**$17.51**
Ship	$982.88	$953.81	$1,936.69	**$1.13**	$2,983.27	$15,376.28	$5,634.11	$23,993.66	**$14.06**	$25,559.71	**$15.19**

Table 12: Base case, Shenzhen - Stuttgart

Urumqi – Stuttgart: Laptop, Fuel $1.5/gallon, 5 ton freight, 1706 Laptops, per unit $600

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$6,067.93		$6,067.93	**$3.56**	$2,983.27	$347.92	$1,884.70	$5,215.89	**$3.06**	$11,283.82	**$6.61**
727	$13,427.63	$27.83	$13,455.46	**$7.88**	$5,966.53	$264.15	$2,894.88	$9,125.56	**$5.35**	$22,581.02	**$13.23**
Rail	$9,814.04	$868.86	$10,682.91	**$6.26**	$2,983.27	$7,481.65	$5,790.33	$16,255.25	**$9.53**	$26,938.16	**$15.78**

Table 13: Base case, Urumqi - Stuttgart

The first thing one should note is that the total transport costs are the same for the three types of aircraft, as these calculations are based on distance and payload. This is the case as all transport modes are traveling along the same route, just the other way around[7]. Yet for sea shipping and rail the costs differ as rates are based on the volumetric size of the goods which are in this case a less than container load (LCL) and the volumetric sizes between laptops and turbochargers differ. As well, sea shipping rates from Shenzhen to Rotterdam are higher than rates from Rotterdam to Shenzhen. The warehousing, inventory during transit, and handling costs are all depending on the value of the goods. Hence these outcomes differ when comparing laptops to turbo chargers.

[7] Head or tail winds are not taken into account

It might seem remarkable that the total costs for transporting laptops, as just mentioned, stay the same, while the costs per laptop are lower than the costs per turbo charger. This happens due to the fact that per unit a laptop weights less than a turbochargers does. Consequently, when transporting 5 tons, more laptops are transported. Henceforth the total value of transport for laptops is about $1 million whereas the total value of turbochargers is less than $750.000.

Comparing the total costs when transporting laptops from east to west, UCA is again in each of the cases the cheapest mode of transport. The differences between the modes are in terms of real values smaller than in the scenarios transporting automotive goods. The Boeing 727 stays the most expensive form of transport in the case of Shenzhen, yet for Urumqi rail is more expensive in this scenario.

From the standard cases it can be concluded that on route between Stuttgart and Shenzhen (turbo chargers) and Shenzhen and Stuttgart (laptops) UCA are considerably cheaper than the, in payload size comparable, Boeing 727. However, compared to the Boeing 777 costs savings of the UCA are somewhat smaller, likely because of the scale advantage of the Boeing 777 of which only the proportion of the payload used for this aircraft are accounted for. As the difference with the last mentioned aircraft is the smallest difference, relatively most costs can be saved on route to Urumqi with no option of flying with the Boeing 777. However, with rail being less dependent on fuel costs than aircraft this mode could become more economically than presented in the base case above when fuel rates would increase. As well the ratios between the other modes could change, the effects of fuel prices will be taken into account in the next section.

5.1.2 Fuel effects

Fuel prices are currently (December 2016) $1.50 per gallon, however the past has proven that these prices fluctuate substantially and with that influence the operation costs greatly. The costs for rail will not change throughout this section as this is a fixed rate not depending on fuel (see chapter 3). Higher prices for shipping are not included in this section, yet they are included in section 5.2.

Note that when fuel costs fluctuate, only transport costs are changing, as cargo costs are not affected by fuel but by time. Hence only transport and total costs are given in tables 14-16, whereas cargo costs are given in appendix 4. The option of aircraft adjusting their speed in response to differences in fuel prices is neglected and out of scope for this thesis. For comparison with the transport costs based on the current $1.50 per gallon, the base case in section 5.1.1 can be consulted. All tables in this section assume 5 tons freight per week. If the fuel rate would decrease to $1.25, this would lead to the following transport costs:

Stuttgart – Shenzhen: Automotive, Fuel $1.25/gallon				
	Total Transport	**Per Turbo**	**Total transport & Cargo**	**Per Turbo**
UCA	$8,658.03	**$11.77**	$12,358.90	**$16.81**
777	$6,823.61	**$ 9.28**	$15,485.00	**$21.06**
727	$19,071.13	**$25.93**	$25,386.04	**$34.52**
Ship	$1,566.05	**$2.13**	$18,438.74	**$25.08**

Shenzhen - Stuttgart: Laptops, Fuel $1.25/gallon				
	Total Transport	**Per Laptop**	**Total transport & Cargo**	**Per Laptop**
UCA	$8,658.03	**$5.07**	$14,195.78	**$8.32**
777	$6,823.61	**$4.00**	$19667.27	**$11.53**
727	$1,9071.13	**$11.17**	$28,226.44	**$16.54**
Ship	$1,936.69	**$1.13**	$25,559.71	**$15.19**

Table 14 (part 1): Fuel rate of $1.25

Stuttgart – Urumqi: Automotive, Fuel $1.25/gallon				
	Total Transport	Per Turbo	Total trans-port & Cargo	Per Turbo
UCA	$5,235.23	**$7.12**	$8,826.98	**$12.00**
727	$12,404.85	**$16.87**	$18,638.62	**$25.35**
Rail	$7389.62	**$10.05**	$18,592.89	**$25.29**

Urumqi - Stuttgart: Laptops, Fuel $1.25/gallon				
	Total Transport	Per Laptop	Total trans-port & Cargo	Per Laptop
UCA	$5,235.23	**$3.07**	$10,451.13	**$6.12**
727	$12,404.85	**$7.27**	$21,530.41	**$12.62**
Rail	$10,682.91	**$6.26**	$26,938.16	**$15.78**

Table 14 (part 2): Fuel rate of $1.25

Table 14 indicates that lower fuel costs can indeed have a substantial impact on the transport costs of flying, however the order of the cheaper to the more expensive mode does not change compared to the base case. Though the costs of the Boeing 727 come very close to rail when it comes to automotive goods, indicating that compared to rail the Boeing 727 becomes relatively more cheap. The same trend is seen when transporting laptops, in this case the Boeing 727 gets relatively more economical opposed to rail than it was before. However when comparing to UCA, the costs of transporting by Boeing 727 are still about twice as much.

When transporting laptops from Shenzhen to Stuttgart, the transport costs per laptop decrease by $0.77 when transporting by UCA, whereas those transported by the Boeing 777 only benefit a $0.27 decrease in costs. Transporting turbo chargers to Shenzhen becomes $1.79 per good cheaper for the UCA whereas this is $0.63 cents for the Boeing 777. This effect is probably because the fuel costs comprise a larger share of total costs for the UCA than for the Boeing 777. Absolute costs savings are largest for the Boeing 727 in all scenarios, that saves $0.97 per laptop and $2.24 per turbo charger. These results suggest that when fuel rates would rise, the costs per unit increase relatively most per Boeing 727, followed by the UCA and lastly the Boeing 777.

Fuel rates are currently expected to rise as they are currently recovering from a ultimate low halfway 2016 (IATA, 2016). When fuel rates rise to $1.75 the following results for aircraft present itself:

Stuttgart – Shenzhen: Automotive, Fuel $1.75/gallon				
	Total Transport	Per Turbo	Total trans-port & Cargo	Per Turbo
UCA	$11,294.78	**$15.36**	$14,995.65	**$20.39**
777	$7751.89	**$10.55**	$16,413.29	**$22.33**
727	$22,350.15	**$30.40**	$28,665.06	**$38.99**
Ship	$1566.05	**$2.13**	$18,438.74	**$25.08**

Shenzhen - Stuttgart: Laptops, Fuel $1.75/gallon				
	Total Transport	Per Laptop	Total trans-port & Cargo	Per Laptop
UCA	11,294.78	**$6.62**	$16,832.53	**$9.86**
777	$7751.89	**$4.54**	$20,595.56	**$12.07**
727	22,350.15	**$13.09**	$31,505.46	**$18.46**
Ship	$1,936.69	**$1.13**	$25,559.71	**$15.19**

Stuttgart – Urumqi: Automotive, Fuel $1.75/gallon				
	Total Transport	Per Turbo	Total trans-port & Cargo	Per Turbo
UCA	$6,900.63	**$9.38**	$10,492.37	**$14.27**
727	$14,506.07	**$19.73**	$20,739.84	**$28.21**
Rail	$7389.62	**$10.05**	$18,592.89	**$25.29**

Urumqi - Stuttgart: Laptops, Fuel $1.75/gallon				
	Total Transport	Per Laptop	Total trans-port & Cargo	Per Laptop
UCA	$6,900.63	**$4.04**	$12,116.52	**$7.10**
727	14,506.07	**$8.50**	$23,631.63	**$13.85**
Rail	10,682.91	**$6.26**	$26,938.16	**$15.78**

Table 15: Fuel rate of $1.75

The results of a price of $2.00 per gallon are given in table 16 on the next page.

Stuttgart – Shenzhen: Automotive, Fuel $2/gallon				
	Total Transport	Per Turbo	Total trans-port & Cargo	Per Turbo
UCA	$12,613.16	**$17.15**	$16,314.02	**$22.19**
777	$8,216.04	**$11.18**	$16,877.43	**$22.96**
727	$23,989.66	**$32.63**	$30,304.57	**$41.22**
Ship	$1566.05	**$2.13**	$18,438.74	**$25.08**

Shenzhen - Stuttgart: Laptops, Fuel $2/gallon				
	Total Transport	Per Laptop	Total trans-port & Cargo	Per Laptop
UCA	12,613.16	**$7.39**	$18,150.90	**$10.64**
777	$8,216.04	**$4.82**	$21,059.70	**$12.34**
727	23,989.66	**$14.06**	$33,144.97	**$19.42**
Ship	$1,936.69	**$1.13**	$25,559.71	**$15.19**

Stuttgart – Urumqi: Automotive, Fuel $2/gallon				
	Total Transport	Per Turbo	Total trans-port & Cargo	Per Turbo
UCA	$7,733.32	**$10.52**	$11,325.07	**$15.40**
727	$15,556.68	**$21.16**	$21,790.45	**$29.63**
Rail	$7389.62	**$10.05**	$18,592.89	**$25.29**

Urumqi - Stuttgart: Laptops, Fuel $2/gallon				
	Total Transport	Per Laptop	Total trans-port & Cargo	Per Laptop
UCA	$7,733.32	**$4.53**	$12,949.21	**$7.59**
727	15,556.68	**$9.12**	$24,682.24	**$14.46**
Rail	10,682.91	**$6.26**	$26,938.16	**$15.78**

Table 16: Fuel rate of $2.00

Logically, the higher the fuel costs get, the higher the share of costs for transport costs opposed to costs of cargo during transit. As expected and indicated by table 15 and 16, the Boeing 777 is the aircraft that is least affected by the increase in fuel prices and therefore moves closer to being the cheapest mode, yet does not reach this position. However, if inventory-time costs would not be taken into account, the Boeing 777 is in all scenarios the cheapest form of air transport. Though the aircraft cannot compete with sea shipping in terms of transport costs.

As the costs for sea shipping and rail in this scenario do not increase with the increase of fuel price, it is visible that even if the costs of fuel would rise, UCA are able to outperform rail when including time-inventory costs. However, looking at the transport costs only, of automotive goods, rail becomes the cheaper mode of transport when the fuel price reaches a level of $2 per gallon. In the other scenarios UCA are also more economical than rail when not incorporating time-inventory costs. Especially when transporting laptops, rail is not a very beneficial option. Even with fuel prices at $2 per gallon, the relatively expensive Boeing 727 is still more economically. On the other routes, the Boeing 727 is the most expensive mode and stays this with an increasing rate.

It can be concluded that fuel effects benefit or worsen aviation in general, yet it depends not only on the mode of transport but also on the type of goods transported how large the impact turns out to be. In this case UCA are affected significantly by increases or decreases in fuel rates, which can have a negative effect on their economic performance, especially when compared to the Boeing 777 or rail if fuel rates are increasing. If the rates would rise enough, the Boeing 777 and rail will eventually become cheaper. Chapter 6 will discuss these results further.

5.1.3 Transit time and scheduling effects

This section calculates the effects of more idle time at the airport and more frequent trains than once a week. For the modes of transport with a max payload of 5 tons (UCA) or of which only a proportion of the costs are calculated, such as the Boeing 777 and rail, a frequency of once a week is assumed in the scenarios in this section (similar to the base case). The effects of more or less freight demand on the frequency of transport is analysed in section 5.2.3.

So far the Boeing 777 is assumed to have no idle time on top of the three hour handling time of the aircraft at any of the airports. However this is in reality often not the case and so a scenario is included in which waiting times at the airports increase with 5 hours. This extra idle time is only relevant for the Boeing 777, as the UCA does not pass by any airports and the 727 is operating for the shipper only. Hence the latter two are independent from schedules or do not have to wait for other goods to be loaded in the same aircraft. Besides, in all fuel scenarios (section 5.1.2) and the base scenario (section 5.1.1), the transport costs of the Boeing 727 are already higher than those of UCA, indicating that adding more hours of idle time at the airport will only make the Boeing 727 less attractive than it already is, and thus will not lead to new insights in the comparison with UCA.

Table 17 below indicates the results for the Boeing 777 with a transport time of in total 10 hours more, for an easy comparison the base results of the Boeing 777 (from table 10 and 12) are given as well. As the longer idle time at the airport does not affect transport costs, these are not included in table 17 but can be found in appendix 4.

Stuttgart – Shenzhen: Automotive							
	Total warehouse	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Turbo**	**Total transport & cargo**	**Per Turbo**
777 base	$2,087.63	$342.47	$6,231.29	$8,661.39	**$11.78**	$15,949.14	**$21.69**
777 + 10h	$2,087.63	$510.34	$6,231.29	$8,829.27	**$12.01**	$16,117.02	**$21.92**

Shenzhen – Stuttgart: Laptops							
	Total warehouse	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Turbo**	**Total transport & cargo**	**Per Turbo**
777 base	$2,983.27	$476.88	$9,383.52	$12,843.67	**$7.53**	$20,131.42	**$11.80**
777 + 10h	$2,983.27	$710.65	$9,383.52	$13,077.43	**$7.66**	$20,365.18	**$11.93**

Table 17: Extra idle time Boeing 777

In both scenarios the total costs of the Boeing 777 increase by 1.1% if total transport time increases by 10 hours. Hence the competitive position of the Boeing decreases slightly to that of the UCA, yet it is still considerably cheaper than the Boeing 727 or shipping.

Besides time effects for the Boeing 777, scheduling effect related to time could also play a role for rail. As mentioned in chapter 4, the train currently moves not one but three times a week from Urumqi to Duisburg. This could have an effect on the rail costs by reducing the cargo costs (the time spend in warehouses), yet also by increasing the transport costs of trucking and extra handling. The results of transporting by rail three times a week are given in table 18.

Urumqi – Stuttgart Laptop – Part 1				
	Train costs	**Truck**	**Total transport**	**Per laptop**
Rail 1	$9,814.04	$868.86	$10,682.91	**$6.26**
Rail 3	$9,814.04	$2606.58	$12,420.62	**$7.28**

Urumqi – Stuttgart Laptop – Part 2							
	Warehouse	**Inventory**	**Handling**	**Total cargo**	**Cargo per Laptop**	**Total**	**Per laptop**
Rail 1	$2,983.27	$7,481.65	$5,790.33	$16,255.25	**$9.53**	$26,938.16	**$15.78**
Rail 3	$994.42	$7,481.65	$17,377.96	$25,854.04	**$15.15**	$38,274.66	**$22.43**

Table 18: Train costs 3 times a week

Table 18 shows that if the train would transport three times a week instead of once, total transport costs increase. The train costs stay the same as these are calculated per share used of the train per kilometre, this is seen in the first row of table 18 (train costs). Yet a big increase can be seen in trucking costs. Instead of once a week, the truck has to drive three times a week. Concerning the cargo costs, a large decrease is seen with respect to warehousing, as goods spend less time in the warehouse. Inventory costs during transit are the same as the same number of goods still make the same trip in terms of hours. However, again a large increase is present with respect to handling costs, more transfers lead to higher direct costs and higher risks of damage.

All in all, total costs increase substantially from $15.78 to $22.43 (42%). That means that the advantage of transporting by train more frequently does not outweigh the transport costs, thus this option is not further considered and from now on train will only be considered once a week. Again, these results will be further discussed in chapter 6.

5.1.4 Inventory time costs

As mentioned in chapter 3, the rate of depreciation, insurance costs and capital costs are difficult to determine. Even though the 20% is well argued for, a lower rate of 15% is considered as well in case the costs are estimated too high. In this way the UCA is surely not estimated too positively. Table 19 presents the results when taking into account the base case, yet with a time-inventory rate of 15%. As transport costs are unaffected by the time-inventory rate, table 19 only depicts the cargo and total costs, transport costs can be reviewed in tables 10-13.

Stuttgart – Shenzhen: Automotive							
	Total warehouse	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Turbo**	**Total**	**Per Turbo**
UCA	$1,735.10	$269.23	$1,254.26	$3,258.58	**$4.43**	$13,234.99	**$18.00**
777	$1,735.10	$256.85	$6,231.29	$8,223.24	**$11.18**	$15,510.99	**$21.09**
777 + 10h	$1,735.10	$382.76	$6,231.29	$8,349.14	**$11.35**	$15,636.89	**$21.26**
727	$3,470.19	$203.13	$1,868.80	$5,542.12	**$7.54**	$26,252.76	**$35.71**
Ship	$1,735.10	$8,281.71	$3,742.77	$13,759.58	**$18.71**	$15,325.63	**$20.83**

Stuttgart – Urumqi: Automotive							
	Total warehouse	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Turbo**	**Total**	**Per Turbo**
UCA	$1,735.10	$187.39	$1,254.26	$3,176.75	**$4.32**	$9,244.68	**$12.57**
727	$3,470.19	$142.27	$1,868.80	$5,481.27	**$7.45**	$18,936.72	**$25.75**
Rail	$1,735.10	$4,029.64	$3,742.77	$9,507.51	**$12.93**	$16,897.13	**$22.98**

Shenzhen – Stuttgart: Laptop							
	Total warehouse	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Turbo**	**Total**	**Per Turbo**
UCA	$2,492.36	$374.90	$2,054.61	$4,921.87	**$2.88**	$19,521.29	**$11.44**
777	$2,492.36	$357.66	$9,383.52	$12,233.54	**$7.17**	$19,696.61	**$11.54**
777 + 10h	$2,492.36	$532.98	$9,383.52	$12,408.86	**$7.27**	$28,789.85	**$16.87**
727	$4,984.72	$282.86	$2,811.63	$8,079.21	**$4.73**	$21,595.37	**$12.65**
Ship	$2,492.36	11,532.21	$5,634.11	$19,658.68	**$11.52**	$19,521.29	**$11.44**

Urumqi – Stuttgart: Laptop							
	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$2,492.36	$260.94	$1,884.70	$4,638.00	**$2.72**	$10,705.93	**$6.27**
727	$4,984.72	$198.12	$2,894.88	$8,077.71	**$4.73**	$21,533.17	**$12.62**
Rail	$2,492.36	$5,611.24	$5,790.33	$13,893.93	**$8.14**	$24,576.84	**$14.40**

Table 19: Base-case with time inventory costs 15%

The 5% decrease in time-inventory costs has no effect on the economic order of transport modes. However the cargo, an thus total, costs for rail and ship get closer to the costs of the Boeing 777 and UCA than they were in previous scenarios. Especially the costs of the share paid for the 5 tons of laptops in the fully loaded Boeing 777 get almost equal to those transported by UCA. Yet, as mentioned, the total cargo costs of rail and sea shipping are logically decreasing most relative to the other modes of transport, as these modes comprise the largest inventory time costs. Generally it can be seen that all cargo costs, and consequently the total costs, of all modes decrease.

5.2 – Current and Future demand

Section 5.1 indicated the results with demand at a base case of 5 tons demand per week and compared different rates of fuel and inventory time costs to this scenario. However currently the demand rates are a lot smaller. This section presents the current demand results in 5.2.1 and takes into account the expected future situation, including different prices for sea shipping and rail, in 5.2.2.

5.2.1 Current Situation

Current demand between Stuttgart and Shenzhen is estimated to be 1609 kg per week, as most goods flying from west to east are automotive (see chapter 4) it is assumed that this current demand consists of these goods. The demand for Automotive goods in Urumqi is only 118 kg per week. The other way around demand mostly exists for high tech electronics. Hence the demand from Shenzhen to Stuttgart is estimated to be 290 kg of laptops per week. It is estimated that no demand is present for laptops from Urumqi. Therefore table 20 below indicates three demand scenarios, that of 1609 kg, 118 kg and 290 kg per week.

Stuttgart – Shenzhen: Automotive Demand: 1609 kg per week								
	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$3,210.41	**$13.57**	$2,087.63	$115.52	$2,334.90	**$9.87**	$5,545.31	**$23.44**
777	$2,610.08	**$11.03**	$671.80	$110.21	$2,790.25	**$11.79**	$5,400.33	**$22.82**
777+10	$2,610.08	**$11.03**	$671.80	$164.23	$2,844.28	**$12.02**	$5,454.36	**$23.05**
727	$6,665.01	**$28.17**	$4,175.27	$87.16	$4,456.80	**$18.84**	$11,121.81	**$47.00**
Ship	$1,270.10	**$5.37**	$671.80	$3,553.41	$5,434.16	**$22.97**	$6,704.25	**$28.33**

Table 20 (part 1) – Current Demand Scenarios

Stuttgart – Urumqi: Automotive Demand: 118 kg per week								
	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$143.20	**$8.25**	$2,087.63	$5.90	$2,094.46	**$120.70**	$2,237.66	**$128.95**
727	$317.55	**$18.30**	$4,175.27	$4.48	$4,180.90	**$240.93**	$4,498.45	**$259.23**
Rail	$1,100.47	**$63.42**	$49.27	$126.80	$273.92	**$15.79**	$1,374.39	**$79.20**

Shenzhen – Stuttgart: Laptops Demand: 290 kg per week								
	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$578.63	**$5.85**	$2,983.27	$28.99	$3,019.17	**$30.50**	$3,597.80	**$36.35**
777	$790.60	**$7.99**	$173.03	$27.66	$752.38	**$7.60**	$1,542.98	**$15.59**
777+10	$790.60	**$7.99**	$173.03	$41.22	$765.94	**$7.74**	$1,556.54	**$15.73**
727	$1,201.28	**$12.14**	$5,966.53	$21.87	$5,998.12	**$60.60**	$7,199.40	**$72.74**
Ship	$1,010.81	**$10.21**	$173.03	$891.82	$1,399.87	**$14.14**	$2,410.68	**$24.36**

Table 20 (part 2) – Current Demand Scenarios

In all current situations the demand per week is smaller than the base scenario of 5 tons. As the Boeing 727 and the UCA are assumed to be operated by the shipper of all the goods, these only operate as often as demand is sufficient to fill up the plane. Hence the frequency of their operations decreases if demand is lower. That is the reason why the transport costs per good for the just mentioned modes are the same as in the base scenario. However in case of the Boeing 777, sea shipping or rail, the costs are calculated per share of the mode used or per volumetric size or kilogram transported each week. Hence the transport costs per good do change for these modes. Yet on the other side, as the frequency per week is fixed to one for the Boeing 777, sea shipping, or rail, their cargo costs per good do not change. That is, the goods wait the same amount of time at the warehouse and have the same transit times. Note that the total cargo costs per week are less, as the total is made up of less goods per week.

The weekly time-inventory costs for the Boeing 727 and UCA do change with demand. Specifically if demand is lower than 5 tons, they increase per good. Again the total is smaller than in the base scenario as the weekly costs are made up from less goods. In short that means that for the Boeing 727 and UCA the total cargo costs per goods change with demand, whereas for the Boeing 777, sea shipping or rail the total transport costs change with demand.

For turbo chargers moving from Stuttgart to Shenzhen the Boeing 777 becomes more economical than the UCA, also if 10 hours idle time is included. Note that these costs are only per share used of the wide-body aircraft. Hence the total transport costs are calculated for the share of the 1609 kg only. Compared to sea shipping or the Boeing 727 the UCA is more cost-effective. Yet when transporting the turbo chargers to Urumqi, rail becomes a lot cheaper than UCA in the demand scenario of 118 kg per week. In this case the UCA would only operate once in every 42 weeks. Hence the very high cargo costs make rail the cheaper option. However also the costs for rail are very high, indicating that transporting the turbo chargers to Urumqi is economically not very attractive.

Compared to UCA, the Boeing 777 is also the cheaper mode when transporting laptops from Shenzhen to Stuttgart, as is sea shipping. Both are likely caused by the extremely low frequency of transport of the UCA leading to very high time-inventory costs. With demand at 290 kg per week the unmanned aircraft would only operate once every 17 weeks.

From this section it can be concluded that in none of the current demand scenarios UCA can outperform the Boeing 777 between Stuttgart and Shenzhen in both directions. Neither rail can be outperformed by the UCA in the scenario from Urumqi to Stuttgart. Though in this case it is unlikely that the option of transport is economically feasible at all. UCA are in all scenarios cheaper than the Boeing 727 and sea shipping. Generally one could say that UCA seem to need a minimum demand rate to operate feasibly and outperform the modes of transport that are already on route and for which you only pay for the share used.

5.2.2 Future Situation

Future demand scenarios can impact the feasibility of UCA compared to the other modes of transport, both positively and negatively. This section incorporates the expected demand rates calculated in chapter 4. Besides, the different rates for shipping and rail are incorporated. As explained in chapter 3 (3.3.2) a lower rate of $0.60 per TEU per km is estimated instead of $0.70 from 2020 onwards. Contrary, shipping rates are expected to rise and are estimated to increase with 25% in 2020. By analysing the changes in demand rates this section can conclude with an indication of up to or from what demand rates certain modes become more or less economical than other. Hence it helps in determining in which scenarios UCA can operate beneficially.

Due to the numerous demand scenarios only the total costs are depicted in table 21 below, again the complete results can be found in appendix 4. On the establishment of the expected demand rates is elaborated in chapter 4. The base case is shown in each of the tables for an easy comparison, as well a demand rate of 7500 kg and 10.000 kg (estimated with base case rates) for a complete comparison.

Stuttgart – Shenzhen: Automotive Demand in kg per week – Total costs per turbo charger only								
	1911 kg	**2867 kg**	**3555 kg**	**3822 kg**	**4740 kg**	***Base case***	***7500 kg***	***10.000 kg***
UCA	$22.14	$19.99	$19.26	$19.08	$18.67	***$18.60***	*$18.51*	*$18.90*
777	$22.56	$22.09	$21.91	$21.85	$21.72	***$21.69***	*$21.52*	*$21.44*
777+10	$22.79	$22.31	$22.13	$22.08	$21.95	***$21.92***	*$21.75*	*$21.67*
727	$44.37	$39.90	$38.33	$37.91	$36.94	***$36.76***	*$36.14*	*$36.47*
Ship	$27.69	$26.55	$26.11	$25.98	$25.65	***$25.08***	*$25.15*	*$24.94*

Stuttgart – Urumqi: Automotive Demand: in kg per week – Total costs per turbo charger only								
	133 kg	**173 kg**	**209 kg**	**266 kg**	**346 kg**	***Base case***	***7500 kg***	***10.000 kg***
UCA	$115.39	$90.72	$76.60	$62.06	$49.75	***$13.14***	*$13.05*	*$13.44*
727	$232.10	$182.77	$154.52	$125.44	$100.80	***$26.85***	*$26.16*	*$26.49*
Rail	$73.49	$63.10	$57.15	$51.02	$45.83	***$25.29***	*$29.37*	*$29.18*

Shenzhen - Stuttgart: Laptops Demand in kg per week – Total costs per laptop only								
	344 kg	**427 kg**	**516 kg**	**1250 kg**	***2500 kg***	***Base case***	***7500 kg***	***10.000 kg***
UCA	$31.63	$26.71	$23.20	$13.43	$10.24	***$9.09***	*$9.11*	*$9.42*
777	$14.95	$14.29	$13.82	$12.49	$12.02	***$11.80***	*$11.73*	*$11.70*
777+10	$15.09	$14.43	$13.95	$12.62	$12.16	***$11.93***	*$11.87*	*$11.84*
727	$63.29	$53.44	$46.41	$26.76	$20.17	***$17.51***	*$17.16*	*$17.42*
Ship	$22.83	$21.23	$20.09	$16.88	$15.75	***$15.19***	*$15.01*	*$14.93*

Urumqi - Stuttgart: Laptops Demand: in kg per week – Total costs per turbo charger only								
	50 kg	**100 kg**	**200 kg**	**500 kg**	**1000 kg**	***Base case***	***7500 kg***	***10.000 kg***
UCA	$178.60	$91.20	$47.51	$21.36	$12.73	***$6.61***	$6.59	$6.86
727	$357.70	$182.89	$95.52	$43.17	$25.86	***$13.23***	$12.92	$13.18
Rail	$66.19	$40.73	$28.01	$20.37	$17.82	***$15.78***	$15.62	$15.53

Table 21 – Future Demand Scenarios

A number of trends are visualised in table 21. First of all it seems to be clear that in general transporting more goods is more economical. Hence for each of the scenarios lower demand indicates higher total costs per good. Especially between Stuttgart and Urumqi and the other way around, experiencing very low demand for freight, total transport and cargo costs are extremely high per product. However, the just mentioned trend of decreasing costs for increasing demand, seems less strong for transporting by the Boeing 777. These costs are all within a range of $11 and $23, whereas the costs for the other aircraft reach above $100 in at least one of the demand scenarios. Also sea shipping costs seems to stay rather constant between $14 and $28.

As mentioned before this more stable rate is likely the case as costs for the Boeing 777 are calculated per share of the mode used. Similarly the costs for sea shipping are also calculated per share transported. However, even though this is also done for rail, these costs appear to be very high in lower demand scenarios as well. Yet this is caused by a combination of relatively high trucking costs and high rail costs. A second trend that is quite obvious are the relatively high costs for the Boeing 727. In fact the old aircraft is the most expensive mode in each of the cases. A likely reason for this are the high crew and operation costs for an aircraft that is transporting only a small amount of goods to divide the costs over. Yet it is too soon to conclude that UCA are more beneficial than, in size comparable, manned aircraft. Section 5.3 will elaborate on this matter.

Looking at Automotive goods from Stuttgart to Shenzhen, UCA seem to be the most economical option compared to all modes, however this ranges between being only 2% more efficient than the Boeing 777 at the demand scenario of 1911 kg, to being 17% more efficient in the base case. Compared to the Boeing 727 the percentages of costs savings are extremely high at 100% (1911 kg) and 98% (5000 kg). Shipping is respectively 25% (1911 kg) and 35% (5000 kg) more expensive than UCA.

UCA are not always the cheapest mode moving automotive goods from Stuttgart to Urumqi, as up until a demand rate of 346 kg rail is a more economical mode of transport. At the base case UCA is more economically than the two other modes, 93% more economical than rail and 104% than the Boeing 727, hence the Boeing is twice as expensive.

Concerning laptops moving from Shenzhen to Stuttgart, sea shipping is cheaper than UCA when demand is up to just above 500 kg, Boeing 777 up until a demand of more than 1250 kg per week. However, UCA can operate at lower rates of 67% (ship) and 23% (Boeing 777) when demand is 5 tons a week. The advantage of UCA is largest opposed to the Boeing 727, as it is 93% cheaper.

Rail is the cheapest option moving laptops to Urumqi if demand is, similar to the case with automotive goods, below 500 kg per week. With higher demand scenarios the UCA becomes the cheapest mode, being 100% cheaper than the Boeing 727 and 149% cheaper than rail at the base scenarios of 5 tons a week.

Generally this section made clear that UCA can operate very cost-effective relatively to the other modes of transport. However they do need a minimum demand rate, in these scenarios of more than 500 kg when comparing to rail and more than 1250 when comparing the transport of laptops with the Boeing 777. Besides the results indicate that the type of goods transported can influence the order of most economical mode of transport. Though in general it seems mostly the demand rate that affects the feasibility and economic order of the transport modes. Chapter 6 will elaborate on this. It also became clear that the Boeing 727 turns out to be the most expensive mode in almost all scenarios of this thesis so far, hence for a more fair comparison the next situation will compare UCA to a similar size manned aircraft with as many as possibly similar assumptions to the UCA.

5.3 – Ideal situation manned aircraft

As is recognised before, the Boeing 727 is an old aircraft, with its largest disadvantage not being very fuel efficient and having a limited range compared to more modern aircraft. Henceforth in almost all cases this aircraft is the most expensive form of transport. The reason why the Boeing 727 is analysed is due to its available data, which was not available at the time of writing this thesis for, for instance, the Airbus 320 that has a similar payload for the long range analysed but is much more efficient. Furthermore very few aircraft with such a small payload yet a very long range currently exist, this will be elaborated on in the discussion.

In order to compare the UCA more fairly to an aircraft of the same size, yet without the costs advantages of no having a crew on board, the costs are recalculated for an as far as possible similar aircraft (from now on called MCA, Manned Cargo Aircraft). Hence this practically means an aircraft with 20% more weight than the UCA, additional crew costs, airport costs, handling costs, and trucking costs to the nearest airport. Further input is taken from the base case and transport time is kept the same as in the 727 case. Results are presented in table 22 on the next page.

As seen in table 22, the costs of the MCA are a little more than twice as much as those of the UCA. Yet they are lower than the costs of the Boeing 727. However the comparison of the MCA with the Boeing 727 is somewhat tricky. As the MCA is assumed to have a capacity of 5 tons (similar to UCA), transport costs per turbo charger or laptop should be compared to the ones of the Boeing 727 transporting 10 tons, as this was the max payload of this aircraft which in that case would fly once a week. Though in that scenario the total costs for trucking are only half the costs as in the scenario for the MCA. Even though one could argue that the total costs for flying the Boeing 727 are a lot higher than the MCA, it is safer to compare the results of the MCA to those of the UCA instead of the Boeing 727. This is valid as, as mentioned before, all characteristics between to two are the same apart from the 20% difference in weight, crew costs, airport costs, handling costs, and trucking costs to the nearest airport.

Comparing the results of the first row indicates a large increase in aircraft operations costs, one of $12,964.28 for Shenzhen and of $9543.81 for Urumqi. Yet these numbers seem rational as crew costs for the MCA are $925/h, accumulating for more or less 12 and 9 hours per flight. These 9 and 12 hours are flight times of the Boeing 727, hence not (even) taking into account the extra hours the UCA makes when flying slower than usual. The other extra transport costs mainly come from the higher fuel economy as the MCA is 20% heavier than the UCA. Furthermore, as just mentioned, shorter flight times for the MCA are considered to result in lower costs for inventory during transit. Yet cargo costs

Stuttgart – Shenzhen: Automotive, Fuel $1.5/gallon, 5 ton freight, 735 turbo chargers, per unit $1000											
	Transport: excl. truck	**Total truck**	**Total Transport**	**Per Turbo**	**Total warehouse**	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Turbo**	**Total**	**Per Turbo**
UCA	$9,976.41		$9,976.41	**$13.57**	$2,087.63	$358.97	$1,254.26	$3,700.87	**$5.03**	$13,677.27	**$18.60**
MCA	$22,940.69	$74.01	$23,014.70	**$31.30**	$2,087.63	$237.26	$3,742.77	$6,067.67	**$8.25**	$29,082.37	**$39.55**

Stuttgart – Urumqi: Automotive, Fuel $1.5/gallon, 5 ton freight, 735 turbo chargers, per unit $1000											
	Transport: excl. truck	**Total truck**	**Total Transport**	**Per Turbo**	**Total warehouse**	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Turbo**	**Total**	**Per Turbo**
UCA	$6,067.93		$6,067.93	**$8.25**	$2,087.63	$249.85	$1,254.26	$3,591.75	**$4.88**	$9,659.68	**$13.14**
MCA	$15,611.74	$55.66	$15,667.40	**$21.31**	$2,087.63	$172.91	$3,742.77	$6,003.32	**$8.16**	$21,670.72	**$29.47**

Shenzhen – Stuttgart: Laptop, Fuel $1.5/gallon, 5 ton freight, 1706 Laptops, per unit $600											
	Transport: excl. truck	**Total truck**	**Total Transport**	**Per Laptop**	**Total warehouse**	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Laptop**	**Total**	**Per Laptop**
UCA	$9,976.41		$9,976.41	**$5.85**	$2,983.27	$499.87	$2,054.61	$5,537.74	**$3.25**	$15,514.15	**$9.09**
MCA	$22,940.69	$74.01	$23,014.70	**$13.49**	$2,983.27	$330.39	$5,634.11	$8,947.77	**$5.24**	$31,962.47	**$18.73**

Urumqi – Stuttgart: Laptop, Fuel $1.5/gallon, 5 ton freight, 1706 Laptops, per unit $600											
	Transport: excl. truck	**Total truck**	**Total Transport**	**Per Laptop**	**Total warehouse**	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Laptop**	**Total**	**Per Laptop**
UCA	$6,067.93		$6,067.93	**$3.56**	$2,983.27	$347.92	$1,884.70	$5,215.89	**$3.06**	$11,283.82	**$6.61**
MCA	$15,611.74	$55.66	$15,667.40	**$9.18**	$2,983.27	$240.78	$5,790.33	$9,014.38	**$5.28**	$24,681.78	**$14.46**

Table 22 – Ideal situation manned cargo aircraft (MCA)

eventually turn out to be higher due to higher costs for cargo handling at airports and more frequent handling, as goods have to transfer on trucks twice. All in all, it is arguable that with a relatively small payload of 5 tons UCA can operate more economically than manned aircraft of a similar capacity. However it should be noted that the fuel costs calculated for the MCA in this section are not very precise.

5.4 Sustainability

As it is out of scope for this thesis to precisely analyse the environmental effects per mode of transport, this section will only depict the fuel usage of the analysed aircraft and describe some broad effects. For now it is sufficient to look at the aircraft only as the options by rail and sea shipping are generally a lot more expensive. Besides, as these modes of transport are calculated per price paid and not per costs made, the fuel usage per trip are unknown.

Table 23 indicates the fuel consumption per aircraft flown between Stuttgart and the two Chinese cities. UCA burn the least fuel, after that the MCA of which the fuel consumption is basically 20% more than that of UCA, as they are assumed 20% heavier. However this rate is, as mentioned in section 5.3, not very precise. Mainly because the MCA would be flying faster (burning more fuel), yet higher (flying more efficiently) than UCA. Though it is still useful for an indication. Furthermore the consumption of the Boeing 727 and Boeing 777 is given. As is the consumption of fuel of the Boeing 777 per 5 tons payload.

Gallons fuel consumption per route		
	Shenzhen - Stuttgart	**Urumqi - Stuttgart**
UCA	5273	3331
777	21536 / 1857*	-
727	6419	4113
MCA	6328	3997

*fuel usage 777 per 5 tons payload

Table 23 – Fuel consumption

With its scale advantage the Boeing 777 is by far the most fuel efficient aircraft. However at the high altitudes this aircraft flies the emissions are much more harmful, as explained in chapter 2. The Boeing 727 is the least fuel efficient aircraft.

It can be concluded that if demand is sufficient and transport by large aircraft, such as the Boeing 777, is available this is likely to be the most environmentally friendly option. However, in all other scenarios the UCA would be the most sustainable solution.

5.5 Concluding remarks

In this chapter it became clear that in many scenarios UCA can operate more economically than the Boeing 777, Boeing 727, sea shipping or rail. However increasing fuel rates can worsen their position towards the Boeing 777 and rail. The extra idle time for the Boeing 777 does not have a large impact on the total costs of goods traveling by this mode, though transporting laptops by rail three times a week instead of once a week increases costs significantly. The largest effects on the economic order of the most cost-effective mode of transport is caused by differences in demand for freight. The latter leads to the conclusion that in general the UCA can be the most economical mode of transport, yet it needs a minimum demand of at least 500 kg per week competing with rail and 1250 kg per week competing with a Boeing 777. A manned aircraft as similar as possible to the UCA would not be economically feasible. Taking into account sustainability the Boeing 777 seems to be the most fuel efficient aircraft. These results will be further discussed in chapter 6.

Chapter 6 – Discussion of the results

From the first until the fifth chapter it became clear that UCA could offer a cheaper and more flexible mode of transport that could connect developing regions to the global world. However, as currently only ideas and prototypes of the unmanned aircraft exist, these expectations were not yet confirmed. This thesis aimed to do so by analysing a UCA carrying 5 tons of goods between Germany and China. Specifically, automotive goods transported from Stuttgart to Shenzhen and Urumqi and Laptops from Urumqi and Shenzhen to Stuttgart. By means of this case study the results of the cost-benefit analysis aim to answer the following question: "*To what extent are UCA beneficial and cost-effective to operate on long-haul routes, compared to all possible modes of transport?"*

Before discussing any of the results the biggest limitations of the thesis will be discussed, as they should be kept in mind when interpreting the results. The largest shortcoming is the comparison with a relatively old aircraft, the Boeing 727, due to the limited available information. However, part of this problem is solved by comparing the UCA with a fictional manned aircraft more similar to the UCA. Another limitation is an assumption made with respect to trucking, costs for trucking are assumed to be the same for each quantity that is shipped, hence the trucking costs transporting 100 kg are the same as costs for 1000 kg due to this simplifications costs including trucking could be over-estimated for small demand scenarios. Lastly, though this is accounted for as much as possible including several scenarios, many of the costs are estimated an based on assumptions. Hence real costs for fuel, devaluation or insurance could be different.

Costs of total transport consisting of both cargo and transit costs were calculated for several scenarios. Results based on a weekly demand of 5 tons a week indicate that UCA can operate beneficially and more economical than the other modes of transport analysed. The UCA is respectively 17%, 98%, and 35% more cost-effective than the Boeing 777, Boeing 727, and sea shipping when transporting automotive goods to Shenzhen. When transporting laptops on the same route to Stuttgart, the cost savings are 23%, 67%, and 93% for the Boeing 777, Boeing 727 and sea shipping respectively. Transporting automotive goods to Urumqi by UCA, at a weekly demand of 5 tons, is 93% more economical than rail and 104% more economical than the Boeing 727. Laptops on this route save 100% and 149% for rail and the Boeing 727 respectively. However, as the different sensitivity analyses indicate, these results cannot be seen as *the* costs savings of UCA with respect to the other modes.

The costs savings calculated in the base case scenario differ when other scenarios are considered. For instance, the costs savings change when fuel prices fluctuate. Fuel rates generally have a great impact on the operational costs of aircraft, yet results of this thesis indicate that impact per aircraft also varies. As the fuel costs comprise a larger share of total operational costs of UCA, fluctuations relatively have a larger impact on UCA than on the Boeing 777. Hence if fuel prices increase to more than $2 per gallon, the Boeing 777 becomes more economical than the UCA. The effect of a 5% decrease in inventory rates has no effect on the economic order of transport modes. However the cargo, an thus total, costs for rail and ship get closer to the costs of the Boeing 777 and UCA than they were in previous scenarios. If the two effects would be combined, for instance higher fuel rates and lower inventory costs, the economic orders of the modes of transport could even change.

Even though the effects mentioned in the previous paragraph do affect the results, they have less impact than the different demand rates proved to have, the 17% costs advantage of the UCA compared to the Boeing 777 can decrease substantially to a costs advantage of only 2% at the demand scenario of 1911 kg. Similarly, at a weekly demand of 500 kg rail can be cheaper whereas the costs compared to UCA increase by 149% if 5 tons would be transported. Those findings Indicate that the amount of freight demand influences the comparison greatly. Hence the latter leads to the conclusion that in general the UCA can be the most economical mode of transport, yet it needs a minimum demand of at least 500 kg per week competing with rail and 1250 kg per week competing with a Boeing 777. This result is rational as the costs for the Boeing 777 and rail are calculated for the only share of the mode, operating on a weekly schedule, used meaning that they can be economical at all considered demand rates in the model.

Whereas the Boeing 777 and rail operate on a weekly schedule, UCA were assumed to only fly when demand has accumulated to 5 tons. Hence when demand was lower than the previously mentioned minimums, inventory time costs at the warehouse are accumulating for numerous weeks. Thus by that much that the UCA becomes less and less economically. This effect also holds for the Boeing 727, which turned out to be the least efficient mode in almost all cases. As this effect could be caused by the old characteristics of this aircraft and therefore not provide enough evidence to conclude that UCA are beneficial to operate, UCA were also compared to an MCA. The MCA, basically a UCA with 20% more weight, a crew on board and incorporating airport rate, also turned out to be about twice as expensive than the UCA. Compared to the Boeing 727 it was slightly cheaper, yet this comparison is tricky. As crew costs are accumulating with $925 per hour, the MCA being more expensive is rational at a payload of only 5 tons. This payload is very small to spread the high costs over, which likely explains the lack of small long-haul aircraft and with that indicates the possibilities for UCA.

Taking all results together it can be concluded that UCA need a minimum demand of 500 kg per week if they would be operating between Stuttgart and Urumqi and competing with rail, and a minimum of 1250 when operating between Stuttgart and Shenzhen and competing with the Boeing 777. Besides the minimum demand necessary, the weekly of demand (above the minimum) and the types of goods also significantly affect the percentage of costs saved when flying UCA. As the overall results are positive for UCA interests rise for more research into the unmanned vehicles.

Many recommendations can be named for further research concerning UCA, especially as currently little research is available. A first and obvious recommendation would be research incorporating more accurate information on both the UCA and manned aircraft. Hence using an existing (once developed) UCA and compare it to more modern aircraft, especially replacing the comparison with the Boeing 727. Besides a research taking in account the possibility of circle trips would give more insight on additional costs savings related to the flexibility of UCA. Besides these quantitative analyses focus on the costs and benefits of UCA, research on the implications for airspace deems necessary as well. If UCA or other point to point connections would prove to be beneficial in most scenarios, it could lead to problems concerning the available airspace and related regulations. Also more can be said about sustainability.

Chapter 7 – Conclusion

Air cargo currently is an expensive mode of transport though very useful for high value goods or goods flowing in a 'just-in-time' supply chain. However regions with not enough freight volume or attractiveness for passengers can hardly enter this fast moving market. UCA have proven to be able to operate as a beneficial mode between two smaller regions in China and Germany that are currently not directly connected. The advantages of UCA related to costs savings on the crew, added productivity and efficiency, and a more lightweight airframe lead to more economical transport compared to sea shipping, rail, the Boeing 777, and the Boeing 727.

High-tech consumer electronics moving from Shenzhen or Urumqi to Stuttgart, or automotive goods moving from Stuttgart to Shenzhen or Urumqi, can be beneficially transported by unmanned cargo aircraft (UCA). The high cargo costs can outweigh lower transportation costs when time-inventory costs (devaluation) are included in the calculations. In many of the analysed scenarios UCA can operate more economical than the Boeing 777, Boeing 727, sea shipping or rail. However increasing fuel rates can worsen their position towards the Boeing 777 and rail, as can different type of goods influence the outcomes. The largest effects on the economic order of the most cost-effective mode of transport is caused by differences in weekly demand for freight (in kg). The latter leads to the conclusion that in general the UCA can be the most economical mode of transport, yet it needs a minimum demand of at least 500 kg per week competing with rail and 1250 kg per week competing with a Boeing 777. A manned aircraft as similar as possible to the UCA would not be economically feasible due to the relatively large share of crew costs that would be spread over relatively little cargo.

Bibliography

Airbus. (2015). *Global Market Forecast 2015.* Blagnac Cedex, France: Airbus S.A.S.

Barnes, G., & Langworthy, P. (2003). The per-mile costs of operating automobiles and trucks. *Humphrey Institute of Public Affairs*.

Boeing. (2007). *727-100/-200 Freighter General Arrangement.* Retrieved from http://www.boeing.com/resources/boeingdotcom/company/about_bca/startup/pdf/freighters/727F.pdf

Boeing. (2014). *World Air Cargo Forecast 2014-2015.* Seatle: Boeing Commercial Airplanes.

Burgen, S. (2014, December 10). The Silk Railway: freight train from China pulls up in Madrid. *The guardian*.

Burnson, P. (2011). *22nd annual state of logistics report - A bumby ride.* WWW.LOGISTICSMGMT.COM: Logistics Management.

Cargo From China. (2016, 06 23). *Cargo types by Sea, Air, and Rail*. Retrieved from Cargo From China: https://cargofromchina.com/sea-air-rail/

Cargo from China. (2016). *Ocean Freight Shipping from China: FCL or LCL?* Retrieved from Cargo from China: https://cargofromchina.com/fcl-lcl/

Chopra, S., & Meindl, P. (2016). *Supply Chain Management: Strategy, Planning, and Operation.* Edingburgh Gate: Pearson Educated Limited.

Cox, J. (2014, 08 11). Aks the Captain: How often is autopilot engaged. (U. Today, Interviewer)

Cummings, M., & Guerlain, S. (2007). Developing Operator Capacity Estimates for Supervisory Control of Autonomous Vehicles. *Human Factors*, 1-15.

De Lange, R. (2016, 10 15). Inside ASML. *Financieel Dagblad*, p. Bijlage.

Dolinayová, A., Loch, M., & Kanis, J. (2015). Modelling the influence of wagon technical parameters on variable costs in rail freight transport. *Research in Transport Economics*, 33-40.

Drewry. (2005). Ship Operating Costs - Annual review and forecast 2005/2006. London.

Emirates. (2016, 06 08). *Emirates Skycargo*. Retrieved from Skycargo: http://www.skycargo.com/english/about-us/our-fleet/index.aspx?plane=6

Eurostat. (15, Retrieved 26-06-16, 12 09). Economic data in high-tech sectors.

Eurostat. (2016). *Eurostatistics. Data for short-term economic analyses 12/2016.* Luxemburg: Publications Office of the European Union,.

German Salary Survey. (2016, 12 15). *Salary Survey in Germany in Truck Driver*. Retrieved from Salary Explorer: www.salaryexplorer.com/salary-survey.php?loc=81&loctype=1&job=239&jobtype=3&type=1

GPO. (2016). Electronic code of Federal Regulartions . In *Part 91- General Operating and Flight Rules* (p. §91.1059 Flight time limitations and rest requirements: One or two pilot crews). Washington DC: Government Publishing Office.

Hallerstrom, N. (2013, December). Modeling Aircraft Loan & Lease Portfolios. *Risk & Reward in Aircraft Backed Finance*. Luxemburg: PK AifFinance.

Hoeben, J. (2014). A value analysis of unmanned aircraft operations for the transportation of high time-value cargo. *Not published* .

IATA. (2016, 12 15). *Jet Fuel Price Development*. Retrieved from iata: http://www.iata.org/publications/economics/fuel-monitor/Pages/price-development.aspx

ICAO. (2011). *Unmanned Aircraft Systems (UAS).* Montreal: International Civil Aviation Organization Cir 328.

Jones, C., & Tuzel, S. (2009). Inventory Investment and the Cost of Capital. JEL classification: E32, E44, G31.

Kaeding, N. (2016, September 7). *Does Your State Tax Business Inventory*. Retrieved from Tax foundation: http://taxfoundation.org/sites/taxfoundation.org/files/docs/InventoryTaxes-01.png

Kasarda, J., & Green, J. (2005). Air cargo as an economic development engine: A note on opportunities and constraints. *Journal of Air Transport Management 11*, 459-462.

Kelly, D. (2008). Forecasting aircraft values: An appraiser's perspective. *Air-finance annual*.

Kilometerafstanden.nl. (2016). *Hoe ver is het vliegen* . Retrieved from Kilometerafstanden.nl: http://www.kilometerafstanden.nl/hoe-ver-is-het-vliegen.htm

Kremers, S. (2012). Onbemande vrachtvlieguitgen: Een model voor een batenanalyse. *Not published*.

Kuipers, B., Manshanden, W., Koops, O., Verweij, C., Veldhuis, J., Rosenberg, F., & Schouten, E. (2007). *Maatschappelijk-economische analyse mainport Schiphol.* Delft/Amsterdam/Huizen: TNO.

Mapper, G. C. (2016, 11 3). *Distance Calculator*. Retrieved from greatcirclemapper: http://www.greatcirclemapper.net/

Moussawi-Haidar, L. (2014). Optimal solution for a cargo revenue management problem with allotment and spot arrivals. *Transportation Research Part E*, 173-191.

Mukkala, K., & Tervo, H. (2013). Air transportation and regional growth: which way does the causality run? *Environment and Planning, volume 46*, 1508-1520.

Nonami, K. (2007). Prospect and Recent Research & Development for Civil Use Autonomous Unmanned Aircraft as UAV and MAV. *Journal of System Design and Dynamics*, Vol. 1, No. 2, pp 120-128.

Oberhofer, P., & Dieplinger, M. (2014). Sustainability in the Transport and Logistics Sector: Lacking Environmental Measures. *Business Strategy and the Environment*, 236-253.

Pieffers, T. (2016, September 28). In twee weken van China naar Duitsland. *Nieuwsblad Transport*, pp. 14-17.

Pomfret, R., & Sourdin, P. (2010). Why do trade costs vary? *Rev World Econ*, 709-730.

Prent, S. (2013). De markt voor onbemande vrachtvliegtuigen. *Not published*.

PUCA. (2016, November 20). *Aircraft (PUCA)*. Retrieved from platfromuca: https://www.platformuca.org/

Rastogi, C., & Arvis, J. (2014). *The Eurasian Connection: Supply-Chain Efficiency along the Modern Silk Route through Central Azia.* Washington D.C.: The World Bank.

Routenet. (2016). *Routeplanner*. Retrieved from Routenet: http://www.routenet.nl/address.aspx

Schumann, U. (2000). Effects of Aircraft Emissions on Ozone, Cirrus Clouds, and Global Climate. *Air & Space Europe - Vol 2*, 29-33.

Slager, B., & Kapteijns, L. (2004). Implementation of cargo revenue management at KLM. *Journal of Revenue and Pricing Management*, 80-90.

Szczudlik-Tatar, J. (2013). China's New Silk Road Diplomacy. *Policy Paper The Polish Institute of International Affairs*, No. 34 (82).

Thatcher, J. (2015, June). *Watch Rates with Interest*. Retrieved from Apics: http://www.apics.org/industry-content-research/publications/apics-magazine-home/apics-magazine---landing-page---everyone/2015/06/16/watch-rates-with-interest

The World Bank. (2009). *Air Freight: A Market Study with Implications for Landlocked Countries.* Washington, D.C.: The World Bank Group.

van de Voorde, E., & de Wit, J. (2013). Luchtvaartlogistiek: grote bewegingen in de markt en onderzoek. *Tijdschrift vervoerswetenschap*, 1-12.

van Hassel, E., Meersman, H., van de Voorde, E., & Vanelslander, T. (2016). Impact of scale increase of conatiner ships on the generalised chain cost. *Maritime Policy & Management*, 192-208.

Vilko, J., & Hallikas, J. (2012). Risk assesment in multimodal supply chains. *Int. J. Production Economics*, 586-595.

Wilson, R. (2015). *26th Annual "State of Logistics Report".* CSCMP Annual.

World Data Bank. (2016, 05 31). *International Civil Aviation Organization, Civil Aviation Statistics of the World and ICAO staff estimates.* Retrieved from World Development Indicators: http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators#

Xing, Y. (2014). China's High-Tech Exports: The Myth and Reality. *Asian Economic Papers. The Earth Institute at Columbia University and the Massachusetts Institute of Technology*, 109-123.

Zhang, A. (2003). Analysis of an international air-cargo hub: the case of Hong Kong. *Journal of Air Transport Management 9*, 123-138.

Zhang, Y., & Zhang, A. (2002). A model of air cargo liberalization: passenger vs. all-cargo carriers. *Transportation Research Part E38*, 175-191.

Appendix 1 - Variables

Variables	H = Hoeben (2014), K = Kremers (2012) G = Groningen, van	
A	Aircrew costs per block hour ($/hour)	H
$C_{A/C\ depreciation}$	Aircraft deprecation Costs ($/week)	H
$C_{depreciation}$	Truck depreciation rate ($/week)	G
$C_{aircrew}$	Aircrew costs ($/week)	H
$C_{airport\ usage}$	Airport user charges ($/week)	H
C_{cargo}	Cargo related costs ($/week)	H
C_{driver}	Salary truck driver ($/week)	K
C_{fuel}	Fuel costs ($/week)	H
$C_{handling}$	Costs for cargo handling ($/week)	H
$C_{inventory}$	Loss of cargo value during transport ($/week)	H
$C_{logistics}$	Costs related to cargo and transportation ($/week)	G
$C_{maintenance}$	Maintenance costs ($/week)	H
C_{toll}		G
$C_{transport}$	Transportation costs ($/week)	H
$C_{warehouse}$	Costs for cargo storage ($/week)	H
d_{AB}	Flight leg distance between airport A and B	H
D_{rate}	Devaluation rate of cargo	G
f	Flight frequency (week=1)	H
FC	Fuel consumption (gallon)	H
$H_{consolidation}$	Charge for the consolidation of cargo ($/$m^3$)	H
$H_{load/unload}$	Charge for loading and unloading of cargo ($/$m^3$)	H
$MAT_{airframe}$	Airframe and systems maintenance materials cost per block hour ($/hr)	H
MAT_{engine}	Engine maintenance materials cost per block hour ($/hr)	H
$MHR_{airframe}$	Number of airframe and systems maintenance man-hours per block hour	H
MHR_{engine}	Number of engine maintenance hours per block hour	H
M_{MTOW}	Maximum take-off weight	H
$P_{A/C\ new}$	Aircraft new price ($)	H
P_{fuel}	Fuel price ($/gallon)	H
P_{spot}	Price on the spot market for container shipping ($/TEU, Twenty Equivalent Unit)	G
Q	Shipment volume (ton)	H
q_{AB}	freight flow between A and B (ton/WEEK)	H
$R_{airport}$	Airport charge rate	H
R_{labor}	Aircraft maintenance labour rate per man-hour ($/hr)	H
ρ	Commodity density (ton/m^3)	H
$Risk_{Damage}$	Risk of damage during handling of cargo	G
ρ_{value}	Commodity value density ($/ton)	H
S	Warehouse rent ($/$m^3$)	H
T_{block}	Block time (hr)	H
T_{rest}	Rest time truck drive (hr)	K
t_{wait}	Average cargo waiting time before transport (hr)	H
$t_{0.5}$	Half-time (hr)	H
U	Average utilization (hr/day)	H
V_{cargo}		H
W	Aircraft deprecation rate (%/day)	H

Appendix 2 – Calculations

2.1 Transport times

If available, transport times are taken from Routenet (Routenet, 2016). In other cases the following calculations are done:

Mode of transport	Distance	Speed	per hour
Boeing 727	3148 km	197 km/h	3148/917 = 3.43h = 3h 26 min
	2784 km	197 km/h	4812/917 = 3.04h = 3h 02 min
	3375 km	197 km/h	3375/917 = 3.68h = 3h 41 min
Boeing 777	9171 km	950 km/h	9171/950 = 9.65h = 9h 39 min

2.2 UCA Assumptions

Size similar to Fokker F27 freighter, minus 20% of the weight. Range is assumed at 10.000 km and fuel usage is determined using information of (Hoeben, 2014).

Appendix 3 Market analysis

Chapter 4 gives the necessary details of the markets between Stuttgart and Shenzhen and Stuttgart and Urumqi for the thesis. However, this appendix elaborates on the types of goods and the air cargo markets, and why these are relevant for this case study.

3.1 types of goods Europe - Asia

As mentioned in chapter 4, a comparison is be made between all modes of transport. In order to do this the two continents of the case study are ideally connected by both land and sea. Besides, as nearly 80 per cent of worldwide long-haul air cargo traffic flies on the east-west trade lanes (Boeing, World Air Cargo Forecast 2014-2015, 2014), it is interesting to analyse a route between an eastern and western continent. This comes down to the continents Europe and Asia. The Europe-Asia market comprises 31 percent of the world's long-haul cargo traffic and approximately 19.6 percent of the total world's air cargo traffic in tonne-kilometres.

With an average annual growth rate of 5.5 percent between 1998 and 2013, growth on this trade rout was slightly higher than the world average growth rate of 5.2 (Boeing, World Air Cargo Forecast 2014-2015, 2014). About 2,130,000 tonnes is transported from Europe to Asia, consisting of mostly general industrial machinery (Boeing, World Air Cargo Forecast 2014-2015, 2014). Somewhat less though only 3 percent, 2,070,000 tonnes, flies the other way, mostly consisting of computers, electrical machinery and apparatus (Boeing, World Air Cargo Forecast 2014-2015, 2014). The main types of goods flying in a certain direction are depicted in figure 1. With tonnage of air cargo being more or less balanced in both directions, 2 million tonnes each way, the percentages of both directions display almost equal real values.

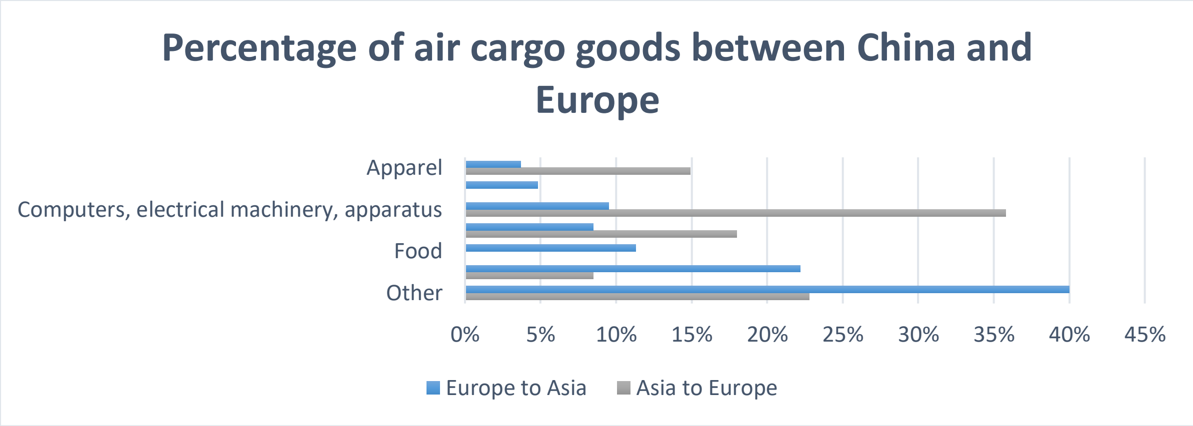


Figure 1 – Percentage per type of good of all air cargo flying between Asia-Europe or Europe-Asia
Source: Boeing, 2014.

The graph evidently indicates that automobile parts and food solely travel from Europe to Asia, also general industrial machinery and 'other' goods flow more towards Asia than the other way around. Apparel (clothing), computers, electrical machinery, apparatus, and documents and small packages flow more from Asia to Europe. With more than one third of all goods moving from Asia to Europe, Computers, electrical machinery and apparatus clearly consist of the largest share. The other way around it is evident that general industrial machinery is, with 22 percent of all goods transported from Europe to Asia, the largest export product by air from Europe to China.

When it comes to high-tech exports that travel by air, the United States and Germany are surpassed by China, with the latter having emerged to be the world's largest high-tech exporting country, producing 16.9 percent of global high-tech exports (Xing, 2014). With this high-tech sector, China presents itself as an interesting candidate for a case study. As mentioned before, just over one third (31 percent) of the long-haul air cargo, moves between Asia and Europe[8] (Boeing, World Air Cargo Forecast 2014-2015, 2014), which makes Europe an interesting counterpart. Besides, from the three largest high-tech exporting continents, only China and Europe are connected by land, which makes it possible to analyse and compare the rail possibilities. Within Europe, Germany clearly is the largest player in terms of the high-technology sector, high-technology manufacturing and knowledge-intensive high-technology services. Germany has the largest turnover and number of enterprises within this sector (Eurostat, Economic data in high-tech sectors, 15, Retrieved 26-06-16). Therefore a region within Germany will be analysed for the case study.

UCA are technically able to fly to anywhere in Germany, though within the scope of this thesis only one city will be analysed. Stuttgart hosts many international technological companies with a focus on automobile technology and industrial technology, yet also Computer technology (ORBIS, 2016). Examples of companies situated here are Robert Bosch GmbH, vector informatik, Hewlett Packard, Mercedes-Benz and Porsche. Geographically Stuttgart is broadly in the middle of Munich and Frankfurt am main, two large (cargo) hub airports. Especially Frankfurt, which is together with Schiphol Airport and Paris CDG of one largest airports in Europe (van de Voorde & de Wit, 2013). For these intercontinental hubs feeding is an important phenomenon, of which a lot happens by trucking under the name of air transport (van de Voorde & de Wit, 2013). Hence concentrating on Stuttgart, cargo

[8] For the purposes of the World Air Cargo Forecast Report, Boeing defined Europe as all 27 member countries of the European Union plus Switzerland, Norway, Iceland, Turkey, Albania, Gibraltar, and all the countries of the former Yugoslavia. Asia is defined as Japan, China, Hong Kong, Taiwan, South Korea, Singapore, the Philippines, Indonesia, Malaysia, Thailand, Vietnam, Macau, Cambodia, New Zealand, and Australia.

that now transfers at *at* least one hub airport, will be able to fly directly by UCA. From Stuttgart the routes to two different regions will be analysed.

To incorporate both a region connected by sea and one by land, two different regions in China are analysed. The first important criterion points out that for this region no direct air trade is currently existing. On top, this region must have some demand or supply of high-value cargo, or at least an indication that this supply or demand might grow with the implementation of UCA. Consequently the first region analysed in the case study, with a sea harbour, is Shenzhen. Shenzhen is large city with a strong focus on high-tech and with a several high-tech companies situated there, such as Huawei, ZTE and Skyworth. Still air cargo mostly flies via Hong Kong which means extra handling time and more transfers imposing the risk of damage. Even on the route between Shenzhen and Frankfurt Am Main or Amsterdam, there are no direct flights and cargo flies indirectly with at least one transfer at Hong Kong. There is no direct rail connection. Interesting side note, Shenzhen also locates DJI, a large drone company. though these drones focus on photography.

Whereas Shenzhen is connected by a sea harbour, yet not by rail, the case for Urumqi is the other way around. Urumqi is connected by rail, though this landlocked city is not connected to a seaport nor directly linked to any region outside East-Asia by its airport, and will therefore complement this research with a case indicating the benefits that UCA can offer to developing regions that still need to make a transition towards the global world economy. Despite Urumqi not being directly connected to the western world by air, the city is along the rail network between Germany and Chongqing/Chengdu. Bedsides, the city is focussing on high tech goods, with institutes as the Xinjiang Machinery Research Institute company Ltd or Urumqi Siruite Mechanical Equipment Co., Ltd. Besides the city is incorporated in the China Western Development strategy. That indicates that this region has potential and products to trade with the rest of the world, yet is in a less competitive position compared to other regions producing similar goods.

Concluding, Stuttgart is a city in Germany that hosts a number of companies focussing on high-tech machinery (automotive) or electronics. Hence this city is not directly connected to two of China's cities which are also active in these industries. Therefore UCA could improve the trade position of these Chinese cities impressively. The next sections will elaborate on the two trade routes including an analysis of the market demand for airfreight with the best available data. IATA gathers as much information as possible about airfreight using customs data, meaning that it is measured how much cargo flies from A to B. Hence this tells nothing about the (de)route the cargo has flown. For this thesis the best available airfreight data comes from IATA statistics in 2010, retrieved by ORTEC Consulting. As the data does not indicate which types of goods are flown between these cities, it is assumed in the analysis that machinery and automotive flies east and electronics west, as this trend is seen in figure 1 and by Rastogi and Arvis (2014).

3.2 Market analysis Stuttgart – Shenzhen

With machinery being such a large part of the Europe-Asia market (see figure 1) Shenzhen is an interesting city to analyse. Machinery is defeasible, often extremely high of value, time sensitive and large. Those characteristics indicate that the less handling (transfers) the better, both in terms of time and risks for damage. Shenzhen, part of the free trade zone, hosts for instance ASML and Brion Technologies Co. Ltd. The former produces large machinery for chips whereas the latter is a company that imports and sells these machines to the Chinese market. Whereas ASML is not situated in Stuttgart, though it outsources work to many companies in Stuttgart (De Lange, 2016), this is the case for (for instance) Mercedes, a brand of Daimler AG. Daimler AG, with headquarters in Stuttgart, and

Mercedes are also situated in Shenzhen. Besides, the Shenzhen BYD Daimler New Technology Company is a joint venture between BYD Auto and Daimler situated in Shenzhen and focussing on electric cars. On top, Shenzhen the hosts a yearly automotive show.

Aside from the automotive industry, of which goods mostly fly west to east, Shenzhen also hosts companies producing high-tech electronics, such as Huawei, ZTE, Skyworth, and DTI. These goods generally fly from east to west. However, as mentioned earlier, cargo often flies a detour. Hence cargo between Stuttgart airport (STR) and Shenzhen airport (SZX) does not fly direct at all, as most cargo that flows between Stuttgart and Shenzhen goes indirectly via the hub airports Frankfurt and Hong Kong. That means that exact numbers on these flows are hard to gather.. The statistics of IATA give some insights, as these numbers present air cargo that has Stuttgart as starting point and Shenzhen as final destination or vice versa. Hence it must be taken into account that this route is not flown directly, meaning that the cargo might go via one or several other airports. The latest available numbers for this thesis are from 2010, which means that it must be taken into account that they are somewhat outdated.

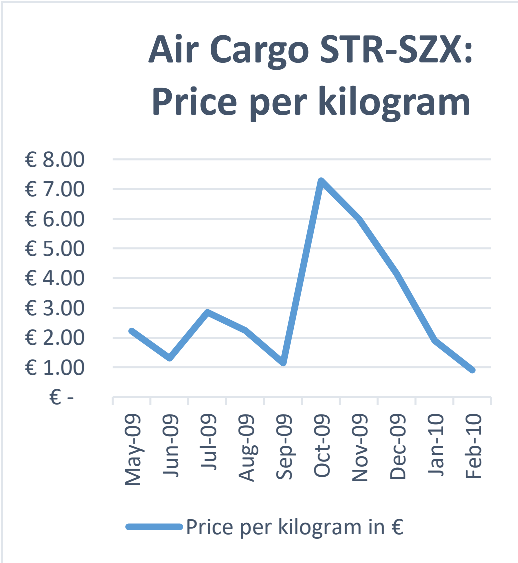


FIGURE 3 AND 4

As seen in the figures above the monthly cargo flow flying from Stuttgart (STR) to Shenzhen International (SZX) is not very large, on average a little less than 5000 kilogram in a month. The price per kilogram, calculated by dividing market revenues by the market weight, vary between $1.01 and $6.69 for one kilogram of freight on the route starting in Stuttgart, with an average of $3.20. Further it is shown that in December 2009 there was excess demand for goods flying from Stuttgart to Shenzhen, henceforth the prices per kilogram were also higher. Yet when comparing December to October and November, this was not the highest price per kilogram. Several explanations can be thought of for this matter, it could be that a most of the cargo on this route flies in the bellies of aircraft, and that in October and November very little passengers wanted to go to Shenzhen resulting in less or smaller aircraft. Or contrary, more passengers wanted to travel to Shenzhen leading to less space in the bellies. Though this could be analysed looking at the passenger data, an explanation to this price difference is out of scope for this thesis.

Often cargo flows are not balanced, the same route yet the other way around shows different figures, this is visualised in figure 5 and 6 below. It can be seen that the average market weight per month on the route Shenzhen to Stuttgart comes down to more or less 900 kilograms. However, this is the case when excluding the months with missing data. When interpreting these months as 'zero air cargo' the average drops to more or less 700 kilograms a month. On this route, the average prices per kilogram are also less than the other way around, $1.81 or $1.55 depending on the interpretation of the missing values. This is in line with the theory mentioned earlier (chapter 1.1), indicating that importing is more expensive for developing countries. It is remarkable that in July 2010 there was a huge peak in air cargo demand, seasonal wise this peak is opposite towards to peak the other way around, in December 2009. However, as this data is only available for one year, it is not possible to conclude trends from it. Besides it is out of scope for this thesis to pay a lot of attention to it.

FIGURE 5 AND 6

It should be noted that both Stuttgart and Shenzhen are quite developed regions that are likely to trade more goods than the data above indicate. In the case of trucking under airport note the data would account for cargo moving from Stuttgart to the largest European cargo airport Frankfurt by truck or cargo moving from Hong Kong, the world largest cargo airport, to Shenzhen. However if companies truck the cargo to the airports themselves and only then hand it over to an airline, the cargo is not registered in this data. That indicates that the current connection directly by aircraft is not beneficial enough, yet that it is likely that more airfreight is flowing between these cities. Hence the estimated current averages of airfreight will be forecasted for the future using the predicted growth rate, yet also including a sensitivity analysis incorporating the extra flow of goods by air when this option becomes relatively cheaper. The tables with average market weights are given in chapter 4.

It can be concluded from the air cargo analysis between Stuttgart and Shenzhen, both directions, that demand for direct airfreight seems to be small and unstable. Comparing the directions it became visible that more goods flow from Stuttgart to Shenzhen than the other way around. The small and unstable demand does not mean that all other goods are shipped over the ocean instead of by air, goods are likely to fly via Frankfurt or Hong Kong and are trucked to and from these major airports.

Taking that together indicates that it is likely that more demand exists than the numbers shown in the figures, yet that direct air transport is not attractive enough to be widely used. This is likely to lead to a boost in airfreight demand if UCA proof to be a cheaper mode of transport. Tables XX and XX indicate estimates of possible boosts in demand. However, as these numbers on airfreight flows are very uncertain and crudely estimated, a sensitivity analysis will be conducted to see the effect of different fright flows. For this route the comparison will be made with air, shipping, and trucking. The next section will depict demand for the city along the modern silk line railway instead of a harbour, Urumqi.

3.3 Market analysis Stuttgart – Urumqi

Landlocked Urumqi has due to its geographical characteristics no possibility to transport via the cheap option of shipping. Though since 2015, the improved Yu'Xin'Ou railway, better known as the modern silk route, is connecting Urumqi and other Chinese cities such as Chongqing, Chengdu, Xian and Lanzhou to Duisburg, Germany. Chapter 4 elaborates on the duration and characteristics of this rail track. Besides rail, cargo currently flies via for instance Shanghai or Beijing, hence a direct flight between Urumqi and anywhere outside Asia is currently not operating. Figure 2 depicts the flow of air cargo between Stuttgart and Urumqi, this flow seems to go only one way as data lacks for the other way around (IATA). However also for the West-East direction in figure 2 a lot of data is missing. Again, this could also be interpreted as 'zero cargo months' instead of missing data, the former results in an average flow of 228 kilograms per month whereas the latter results in an average flow of 364 kilograms per month. Consistent with the previous section, the option of 364, when excluding the zero data months, is assumed.

With respect to the prices paid for air cargo between these routes, figure x shows that the price per kilogram of cargo in December 2009 was extremely high, $33.44 this is just after a month of high demand for this route. The price drops again when this demand for freight drops as well. It could have been an emergency shipment or any other influence on supply and demand. Again, the data is too limited to say something about this and it is out of scope for this analysis.

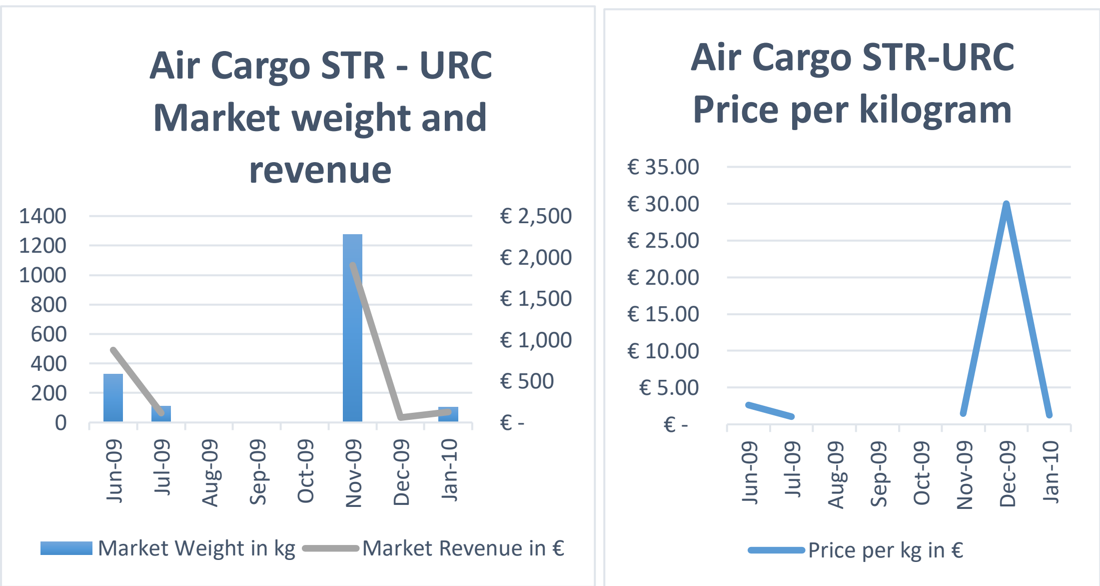
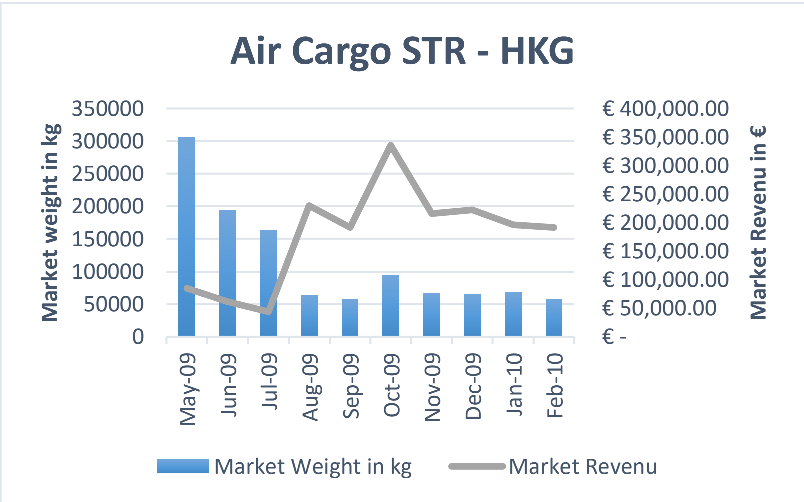


FIGURE 7 AND 8

It can be concluded that, at least from air freight demand, currently very little and unstable demand is flowing on the market between Stuttgart and Urumqi. Urumqi only seems to import cargo and thus not export at all by air, as there is no cargo flying the other way around. When looking at similar cities to Urumqi, such as Lanzhou, the same phenomenon holds. Little cargo flies from Stuttgart to Lanzhou, nothing the other way around. This is understandable as the prices seem to get pretty high on this route. Compared to the previous analyzed route, Stuttgart - Shenzhen, cargo flows are even more unstable and a similar trend seems that demand is higher for Stuttgart-China than the other way around. That, as said in the literature, leads to higher prices to export (from China). Prices for cargo do in both cases not move 1:1 with demand, meaning that the highest demand not necessarily means the highest price. Hence an explanation for that is out of scope for this analysis, besides these prices are not costs as they might also include profits, this thesis focuses on costs.

3.4 Additional Freight info

The figures below indicate that the demand for airfreight is a lot higher (on average more than 10 times) from Stuttgart to Hong Kong than demand between Stuttgart and Shenzhen. Yet both Chinese cities are quite close, hence this could indicate that more goods are exported by Shenzhen via the hub airport of Hong Kong.



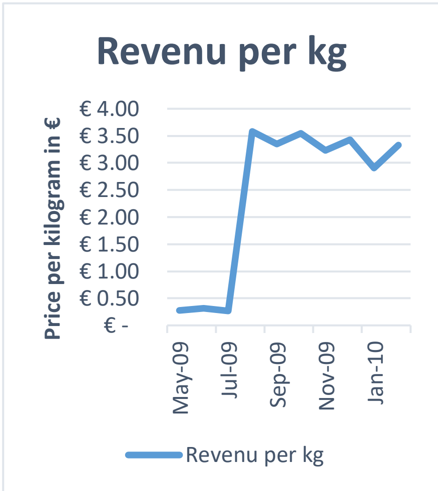


FIGURE 9 AND 10

Appendix 4 – Results

4.1 Base case

Stuttgart – Shenzhen: Automotive											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$9,976.41		$9,976.41	$13.57	$2,087.63	$358.97	$1,254.26	$3,700.87	$5.03	$13,677.27	$18.60
777	$6,897.19	$390.56	$7287.75	$ 9.91	$2,087.63	$342.47	$6,231.29	$8,661.39	$11.78	$15,949.14	$21.69
777 +10h	$6,897.19	$390.56	$7287.75	$ 9.91	$2,087.63	$510.34	$6,231.29	$8,829.27	$12.01	$16,117.02	$21.92
727	$20,674.64	$37.00	$20,711.64	$28.17	$4,175.27	$270.84	$1,868.80	$6,314.91	$8.59	$27,026.55	$36.76
Ship	$612.24	$953.81	$1566.05	$ 2.13	$2,087.63	$11,042.28	$3,742.77	$16,872.69	$22.95	$18,438.74	$25.08

Stuttgart – Urumqi: Automotive											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$6,067.93		$6,067.93	$8.25	$2,087.63	$249.85	$1,254.26	$3,591.75	$4.88	$9,659.68	$13.14
727	$13,427.63	$27.83	$13,506.65	$18.30	$4,175.27	$189.70	$1,868.80	$6,233.77	$8.48	$19.740.42	$26.85
Rail	$6,520.76	$868.86	$7389.62	$10.05	$2,087.63	$5,372.85	$3,742.77	$11,203.26	$15.24	$18,592.88	$25.29

Shenzhen – Stuttgart: Laptop											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$9,976.41		$9,976.41	$5.85	$2,983.27	$499.87	$2,054.61	$5,537.74	$3.25	$15,514.15	$9.09
777	$6,897.19	$390.56	$7287.75	$4.27	$2,983.27	$476.88	$9,383.52	$12,843.67	$7.53	$20,131.42	$11.80
777 +10h	$6,897.19	$390.56	$7287.75	$4.27	$2,983.27	$710.65	$9,383.52	$13,077.43	$7.66	$20,365.18	$11.93
727	$20,674.64	$37.00	$20,711.64	$12.14	$5,966.53	$377.14	$2,811.63	$9,155.31	$5.37	$29,866.95	$17.51
Ship	$982.88	$953.81	$1,936.69	$1.13	$2,983.27	$15,376.28	$5,634.11	$23,993.66	$14.06	$25,559.71	$15.19

Urumqi – Stuttgart: Laptop											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$6,067.93		$6,067.93	$3.56	$2,983.27	$347.92	$1,884.70	$5,215.89	$3.06	$11,283.82	$6.61
727	$13,427.63	$27.83	$13,455.46	$7.88	$5,966.53	$264.15	$2,894.88	$9,125.56	$5.35	$22,581.02	$13.23
Rail	$9,814.04	$868.86	$10,682.91	$6.26	$2,983.27	$7,481.65	$5,790.33	$16,255.25	$9.53	$26,938.16	$15.78

4.2 Fuel effects

4.2.1. Fuel $1.25

Stuttgart – Shenzhen: Automotive

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$8,658.03		$8,658.03	$11.77	$2,087.63	$358.97	$1,254.26	$3,700.87	$5.03	$12,358.90	$16.81
777	$6,433.05	$390.56	$6,823.61	$ 9.28	$2,087.63	$342.47	$6,231.29	$8,661.39	$11.78	$15,485.00	$21.06
777 +10h	$6,433.05	$390.56	$6823.61	$ 9.28	$2,087.63	$510.34	$6,231.29	$8,829.27	$12.01	$15,652.87	$21.29
727	$19,035.13	$37.00	$19071.13	$25.93	$4,175.27	$270.84	$1,868.80	$6,314.91	$8.59	$25,386.04	$34.52
Ship	$612.24	$953.81	$1566.05	$2.13	$2,087.63	$11,042.28	$3,742.77	$16,872.69	$22.95	$18,438.74	$25.08

Stuttgart – Urumqi: Automotive

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$5,235.23		$5,235.23	$7.12	$2,087.63	$249.85	$1,254.26	$3,591.75	$4.88	$8,826.98	$12.00
727	$12,377.02	$27.83	$12,404.85	$16.87	$4,175.27	$189.70	$1,868.80	$6,233.77	$8.48	$18,638.62	$25.35
Rail	$6,520.76	$868.86	$7389.62	$10.05	$2,087.63	$5,372.85	$3,742.77	$11,203.26	$15.24	$18,592.89	$25.29

Shenzhen – Stuttgart: Laptop

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$8,658.03		$8,658.03	$5.07	$2,983.27	$499.87	$2,054.61	$5,537.74	$3.25	$14,195.78	$8.32
777	$6,433.05	$390.56	$6,823.61	$4.00	$2,983.27	$476.88	$9,383.52	$12,843.67	$7.53	$19667.27	$11.53
777 +10h	$6,433.05	$390.56	$6823.61	$4.00	$2,983.27	$710.65	$9,383.52	$13,077.43	$7.66	$19.901.04	$11.66
727	$19,035.13	$37.00	$1,9071.13	$11.17	$5,966.53	$377.14	$2,811.63	$9,155.31	$5.37	$28,226.44	$16.54
Ship	$982.88	$953.81	$1,936.69	$1.13	$2,983.27	$15,376.28	$5,634.11	$23,993.66	$14.06	$25,559.71	$15.19

Urumqi – Stuttgart: Laptop

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$5,235.23		$5,235.23	$3.07	$2,983.27	$347.92	$1,884.70	$5,215.89	$3.06	$10,451.13	$6.12
727	$12,377.02	$27.83	$12,404.85	$7.27	$5,966.53	$264.15	$2,894.88	$9,125.56	$5.35	$21,530.41	$12.62
Rail	$9,814.04	$868.86	$10,682.91	$6.26	$2,983.27	$7,481.65	$5,790.33	$16,255.25	$9.53	$26,938.16	$15.78

4.2.2 Fuel $1.75

Stuttgart – Shenzhen: Automotive

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$11,294.78		$11,294.78	$15.36	$2,087.63	$358.97	$1,254.26	$3,700.87	$5.03	$14,995.65	$20.39
777	$7,361.33	$390.56	$7751.89	$10.55	$2,087.63	$342.47	$6,231.29	$8,661.39	$11.78	$16,413.29	$22.33
777 +10h	$7,361.33	$390.56	$7751.89	$10.55	$2,087.63	$510.34	$6,231.29	$8,829.27	$12.01	$16,545.16	$22.56
727	$22,314.15	$37.00	$22,350.15	$30.40	$4,175.27	$270.84	$1,868.80	$6,314.91	$8.59	$28,665.06	$38.99
Ship	$612.24	$953.81	$1566.05	$2.13	$2,087.63	$11,042.28	$3,742.77	$16,872.69	$22.95	$18,438.74	$25.08

Stuttgart – Urumqi: Automotive

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$6,900.63		$6,900.63	$9.38	$2,087.63	$249.85	$1,254.26	$3,591.75	$4.88	$10,492.37	$14.27
727	$14,478.24	$27.83	$14,506.07	$19.73	$4,175.27	$189.70	$1,868.80	$6,233.77	$8.48	$20,739.84	$28.21
Rail	$6,520.76	$868.86	$7389.62	$10.05	$2,087.63	$5,372.85	$3,742.77	$11,203.26	$15.24	$18,592.89	$25.29

Shenzhen – Stuttgart: Laptop

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$11,294.78		$11,294.78	$6.62	$2,983.27	$499.87	$2,054.61	$5,537.74	$3.25	$16,832.53	$9.86
777	$7,361.33	$390.56	$7751.89	$4.54	$2,983.27	$476.88	$9,383.52	$12,843.67	$7.53	$20,595.56	$12.07
777 +10h	$7,361.33	$390.56	$7751.89	$4.54	$2,983.27	$710.65	$9,383.52	$13,077.43	$7.66	$20,829.32	$12.21
727	$22,314.15	$37.00	$22,350.15	$13.09	$5,966.53	$377.14	$2,811.63	$9,155.31	$5.37	$31,505.46	$18.46
Ship	$982.88	$953.81	$1,936.69	$1.13	$2,983.27	$15,376.28	$5,634.11	$23,993.66	$14.06	$25,559.71	$15.19

Urumqi – Stuttgart: Laptop

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$6,900.63		$6,900.63	$4.04	$2,983.27	$347.92	$1,884.70	$5,215.89	$3.06	$12,116.52	$7.10
727	$14,478.24	$27.83	$14,506.07	$8.50	$5,966.53	$264.15	$2,894.88	$9,125.56	$5.35	$23,631.63	$13.85
Rail	$9,814.04	$868.86	$10,682.91	$6.26	$2,983.27	$7,481.65	$5,790.33	$16,255.25	$9.53	$26,938.16	$15.78

4.2.3 Fuel $2.00

Stuttgart – Shenzhen: Automotive

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$12,613.16		$12,613.16	$17.15	$2,087.63	$358.97	$1,254.26	$3,700.87	$5.03	$16,314.02	$22.19
777	$7,825.48	$390.56	$8,216.04	$11.18	$2,087.63	$342.47	$6,231.29	$8,661.39	$11.78	$16,877.43	$22.96
777 +10h	$7,825.48	$390.56	$8,216.04	$11.18	$2,087.63	$510.34	$6,231.29	$8,829.27	$12.01	$17,045.30	$23.18
727	$23,953.66	$37.00	$23,989.66	$32.63	$4,175.27	$270.84	$1,868.80	$6,314.91	$8.59	$30,304.57	$41.22
Ship	$612.24	$953.81	$1566.05	$2.13	$2,087.63	$11,042.28	$3,742.77	$16,872.69	$22.95	$18,438.74	$25.08

Stuttgart – Urumqi: Automotive

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$7,733.32		$7,733.32	$10.52	$2,087.63	$249.85	$1,254.26	$3,591.75	$4.88	$11,325.07	$15.40
727	$15,528.85	$27.83	$15,556.68	$21.16	$4,175.27	$189.70	$1,868.80	$6,233.77	$8.48	$21,790.45	$29.63
Rail	$6,520.76	$868.86	$7389.62	$10.05	$2,087.63	$5,372.85	$3,742.77	$11,203.26	$15.24	$18,592.89	$25.29

Shenzhen – Stuttgart: Laptop

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$12,613.16		$12,613.16	$7.39	$2,983.27	$499.87	$2,054.61	$5,537.74	$3.25	$18,150.90	$10.64
777	$7,825.48	$390.56	$8,216.04	$4.82	$2,983.27	$476.88	$9,383.52	$12,843.67	$7.53	$21,059.70	$12.34
777 +10h	$7,825.48	$390.56	$8,216.04	$4.82	$2,983.27	$710.65	$9,383.52	$13,077.43	$7.66	$21,293.47	$12.48
727	$23,953.66	$37.00	$23,989.66	$14.06	$5,966.53	$377.14	$2,811.63	$9,155.31	$5.37	$33,144.97	$19.42
Ship	$982.88	$953.81	$1,936.69	$1.13	$2,983.27	$15,376.28	$5,634.11	$23,993.66	$14.06	$25,559.71	$15.19

Urumqi – Stuttgart: Laptop

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$7,733.32		$7,733.32	$4.53	$2,983.27	$347.92	$1,884.70	$5,215.89	$3.06	$12,949.21	$7.59
727	$15,528.85	$27.83	$15,556.68	$9.12	$5,966.53	$264.15	$2,894.88	$9,125.56	$5.35	$24,682.24	$14.46
Rail	$9,814.04	$868.86	$10,682.91	$6.26	$2,983.27	$7,481.65	$5,790.33	$16,255.25	$9.53	$26,938.16	$15.78

4.3 Time inventory rate 15%

Stuttgart – Shenzhen: Automotive

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$9,976.41		$9,976.41	$13.57	$1,735.10	$269.23	$1,254.26	$3,258.58	$4.43	$13,234.99	$18.00
777	$6,897.19	$390.56	$7287.75	$ 9.91	$1,735.10	$256.85	$6,231.29	$8,223.24	$11.18	$15,510.99	$21.09
777 +10h	$6,897.19	$390.56	$7287.75	$ 9.91	$1,735.10	$382.76	$6,231.29	$8,349.14	$11.35	$15,636.89	$21.26
727	$20,674.64	$37.00	$20,711.64	$28.17	$3,470.19	$203.13	$1,868.80	$5,542.12	$7.54	$26,252.76	$35.71
Ship	$612.24	$953.81	$1566.05	$ 2.13	$1,735.10	$8,281.71	$3,742.77	$13,759.58	$18.71	$15,325.63	$20.83

Stuttgart – Urumqi: Automotive

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$6,067.93		$6,067.93	$8.25	$1,735.10	$187.39	$1,254.26	$3,176.75	$4.32	$9,244.68	$12.57
727	$13,427.63	$27.83	$13,506.65	$18.30	$3,470.19	$142.27	$1,868.80	$5,481.27	$7.45	$18,936.72	$25.75
Rail	$6,520.76	$868.86	$7389.62	$10.05	$1,735.10	$4,029.64	$3,742.77	$9,507.51	$12.93	$16,897.13	$22.98

Shenzhen – Stuttgart: Laptop

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$9,976.41		$9,976.41	$5.85	$2,492.36	$374.90	$2,054.61	$4,921.87	$2.88	$14,898.28	$8.73
777	$6,897.19	$390.56	$7287.75	$4.27	$2,492.36	$357.66	$9,383.52	$12,233.54	$7.17	$19,521.29	$11.44
777 +10h	$6,897.19	$390.56	$7287.75	$4.27	$2,492.36	$532.98	$9,383.52	$12,408.86	$7.27	$19,696.61	$11.54
727	$20,674.64	$37.00	$20,711.64	$12.14	$4,984.72	$282.86	$2,811.63	$8,079.21	$4.73	$28,789.85	$16.87
Ship	$982.88	$953.81	$1,936.69	$1.13	$2,492.36	$11,532.21	$5,634.11	$19,658.68	$11.52	$21,595.37	$12.65

Urumqi – Stuttgart: Laptop

	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$6,067.93		$6,067.93	$3.56	$2,492.36	$260.94	$1,884.70	$4,638.00	$2.72	$10,705.93	$6.27
727	$13,427.63	$27.83	$13,455.46	$7.88	$4,984.72	$198.12	$2,894.88	$8,077.71	$4.73	$21,533.17	$12.62
Rail	$9,814.04	$868.86	$10,682.91	$6.26	$2,492.36	$5,611.24	$5,790.33	$13,893.93	$8.14	$24,576.84	$14.40

4.4 Different demand rates

4.4.1 Stuttgart – Shenzhen: Automotive demand 1,609 – 10,000 kg

Stuttgart – Shenzhen: Automotive, Demand 1609

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$3,210.41		$3,210.41	$13.57	$2,087.63	$115.52	$131.75	$2,334.90	$9.87	$5,545.31	$23.44
777	$2,219.52	$390.56	$2,610.08	$11.03	$671.80	$110.21	$2,008.25	$2,790.25	$11.79	$5,400.33	$22.82
777 +10	$2,219.52	$390.56	$2,610.08	$11.03	$671.80	$164.23	$2,008.25	$2,844.28	$12.02	$5,454.36	$23.05
727	$6,653.10	$11.91	$6,665.01	$28.17	$4,175.27	$87.16	$194.38	$4,456.80	$18.84	$11,121.81	$47.00
Ship	$316.29	$953.81	$1,270.10	$5.37	$671.80	$3,553.41	$1,208.95	$5,434.16	$22.97	$6,704.25	$28.33

Stuttgart – Shenzhen: Automotive, Demand 1911, Shipping rate $781.25 per TEU

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$3,812.98		$3,812.98	$13.57	$2,087.63	$137.20	$185.15	$2,409.98	$8.58	$6,222.97	$22.14
777	$2,636.11	$390.56	$3,026.67	$10.77	$797.89	$130.89	$2,383.71	$3,312.49	$11.79	$6,339.16	$22.56
777 +10	$2,636.11	$390.56	$3,026.67	$10.77	$797.89	$195.05	$2,383.71	$3,376.65	$12.02	$6,403.32	$22.79
727	$7,901.85	$14.14	$7,915.99	$28.17	$4,175.27	$103.51	$273.85	$4,552.63	$16.20	$12,468.62	$44.37
Ship	$375.66	$953.81	$1,329.46	$4.73	$797.89	$4,220.36	$1,434.22	$6,452.48	$22.96	$7,781.94	$27.69

Stuttgart – Shenzhen: Automotive, Demand 2867, Shipping rate $781.25 per TEU

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$5,720.47		$5,720.47	$13.57	$2,087.63	$205.84	$414.07	$2,707.54	$6.42	$8,428.01	$19.99
777	$3,954.85	$390.56	$4,345.41	$10.31	$1,197.05	$196.37	$3,573.07	$4,966.49	$11.78	$9,311.90	$22.09
777 +10	$3,954.85	$390.56	$4,345.41	$10.31	$1,197.05	$292.63	$3,573.07	$5,062.75	$12.01	$9,408.16	$22.31
727	$11,854.84	$21.22	$11,876.06	$28.17	$4,175.27	$155.30	$615.09	$4,945.66	$11.73	$16,821.72	$39.90
Ship	$563.58	$953.81	$1,517.39	$3.60	$1,197.05	$6,331.64	$2,147.84	$9,676.54	$22.95	$11,193.93	$26.55

Stuttgart – Shenzhen: Automotive, Demand 3822, Shipping rate $781.25 per TEU

	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$7,625.97		$7,625.97	$13.57	$2,087.63	$274.40	$733.84	$3,095.87	$5.51	$10,721.83	$19.08
777	$5,272.21	$390.56	$5,662.78	$10.08	$1,595.79	$261.78	$4,762.45	$6,620.02	$11.78	$12,282.79	$21.85
777 +10	$5,272.21	$390.56	$5,662.78	$10.08	$1,595.79	$390.10	$4,762.45	$6,748.34	$12.01	$12,411.12	$22.08
727	$15,803.70	$28.29	$15,831.98	$28.17	$4,175.27	$207.03	$1,092.23	$5,474.52	$9.74	$21,306.51	$37.91
Ship	$751.31	$953.81	$1,705.12	$3.03	$1,595.79	$8,440.72	$2,861.47	$12,897.98	$22.95	$14,603.10	$25.98

Stuttgart – Shenzhen: Automotive, Demand 3555, Shipping rate $ 976.56 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$7,093.23		$7,093.23	$13.57	$2,087.63	$255.23	$635.25	$2,978.11	$5.70	$10,071.34	$19.26
777	$4,903.90	$390.56	$5,294.47	$10.13	$1,484.31	$243.49	$4,429.79	$6,157.60	$11.78	$11,452.06	$21.91
777 +10	$4,903.90	$390.56	$5,294.47	$10.13	$1,484.31	$362.85	$4,429.79	$6,276.96	$12.01	$11,571.42	$22.13
727	$14,699.67	$26.31	$14,725.98	$28.17	$4,175.27	$192.57	$945.10	$5,312.93	$10.16	$20,038.91	$38.33
Ship	$698.83	$953.81	$1,652.63	$3.16	$1,484.31	$7,851.06	$2,661.88	$11,997.25	$22.95	$13,649.88	$26.11

Stuttgart – Shenzhen: Automotive, Demand 4740, Shipping rate $ 976.56 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$9,457.63		$9,457.63	$13.57	$2,087.63	$340.31	$1,127.39	$3,555.33	$5.10	$13,012.96	$18.67
777	$6,538.54	$390.56	$6,929.10	$9.94	$1,979.08	$324.66	$5,906.93	$8,210.67	$11.78	$15,139.77	$21.72
777 +10	$6,538.54	$390.56	$6,929.10	$9.94	$1,979.08	$483.80	$5,906.93	$8,369.82	$12.01	$15,298.91	$21.95
727	$19,599.56	$35.08	$19,634.64	$28.17	$4,175.27	$256.76	$1,679.51	$6,111.53	$8.77	$25,746.17	$36.94
Ship	$931.77	$953.81	$1,885.58	$2.71	$1,979.08	$10,468.08	$3,548.16	$15,995.32	$22.95	$17,880.90	$25.65

Stuttgart – Shenzhen: Automotive, Demand 7500, Current shipping rate											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$14,964.61		$14,964.61	$13.57	$2,087.63	$538.46	$2,824.28	$5,450.38	$4.94	$20,414.99	$18.51
777	$10,345.78	$390.56	$10,736.35	$9.73	$3,131.45	$513.70	$9,354.87	$13,000.02	$11.79	$23,736.37	$21.52
777 +10	$10,345.78	$390.56	$10,736.35	$9.73	$3,131.45	$765.51	$9,354.87	$13,251.84	$12.01	$23,988.18	$21.75
727	$31,011.96	$55.51	$31,067.47	$28.17	$4,175.27	$406.26	$4,208.33	$8,789.85	$7.97	$39,857.32	$36.14
Ship	$1,474.32	$953.81	$2,428.13	$2.20	$3,131.45	16,563.42	$5,616.92	$25,311.80	$22.95	$27,739.93	$25.15

Stuttgart – Shenzhen: Automotive, Demand 10000 – Current Shipping rate											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$19,952.81		$19,952.81	$13.57	$2,087.63	$717.95	$5,038.43	$7,844.01	$5.33	$27,796.82	$18.90
777	$13,794.38	$390.56	$14,184.94	$9.65	$4,175.27	$684.93	$12,487.08	$17,347.28	$11.80	$31,532.22	$21.44
777 +10	$13,794.38	$390.56	$14,184.94	$9.65	$4,175.27	$1,020.68	$12,487.08	$17,683.03	$12.02	$31,867.97	$21.67
727	$41,349.28	$74.01	$41,423.29	$28.17	$4,175.27	$541.68	$7,496.25	$12,213.19	$8.30	$53,636.49	$36.47
Ship	$1,965.76	$953.81	$2,919.57	$1.99	$4,175.27	22,084.56	$7,496.25	$33,756.08	$22.95	$36,675.65	$24.94

4.4.2 Stuttgart Urumqi: Automotive demand 118 – 10,000 kg

Stuttgart – Urumqi: Automotive, Demand 118, Rail rate $0.70											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$143.20		$143.20	$8.25	$2,087.63	$5.90	$0.93	$2,094.46	$120.70	$2,237.66	$128.95
727	$316.89	$0.66	$317.55	$18.30	$4,175.27	$4.48	$1.15	$4,180.90	$240.93	$4,498.45	$259.23
Rail	$231.61	$868.86	$1,100.47	$63.42	$49.27	$126.80	$97.86	$273.92	$15.79	$1,374.39	$79.20

Stuttgart – Urumqi: Automotive, Demand 133, Rail rate $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$161.41		$161.41	$8.25	$2,087.63	$6.65	$1.14	$2,095.42	$107.13	$2,256.83	$115.39
727	$357.17	$0.74	$357.92	$18.30	$4,175.27	$5.05	$1.45	$4,181.77	$213.80	$4,539.68	$232.10
Rail	$261.05	$868.86	$1,129.91	$57.77	$55.53	$142.92	$109.02	$307.47	$15.72	$1,437.39	$73.49

Stuttgart – Urumqi: Automotive, Demand 173, Rail rate $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$209.95		$209.95	$8.25	$2,087.63	$8.64	$1.83	$2,098.11	$82.47	$2,308.06	$90.72
727	$464.60	$0.96	$465.56	$18.30	$4,175.27	$6.56	$2.40	$4,184.23	$164.47	$4,649.79	$182.77
Rail	$339.57	$868.86	$1,208.42	$47.50	$72.23	$185.90	$138.81	$396.94	$15.60	$1,605.37	$63.10

Stuttgart – Urumqi: Automotive, Demand 209, Rail rate $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$253.64		$253.64	$8.25	$2,087.63	$10.44	$2.59	$2,100.66	$68.35	$2,354.30	$76.60
727	$561.27	$1.16	$562.44	$18.30	$4,175.27	$7.93	$3.46	$4,186.66	$136.22	$4,749.10	$154.52
Rail	$410.23	$868.86	$1,279.09	$41.62	$87.26	$224.59	$165.62	$477.46	$15.53	$1,756.55	$57.15

Stuttgart – Urumqi: Automotive, Demand 266, Rail rate $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$322.81		$322.81	$8.25	$2,087.63	$13.29	$4.04	$2,104.97	$53.81	$2,427.78	$62.06
727	$714.35	$1.48	$715.83	$18.30	$4,175.27	$10.09	$5.53	$4,190.90	$107.14	$4,906.73	$125.44
Rail	$522.11	$868.86	$1,390.97	$35.56	$111.06	$285.84	$208.06	$604.96	$15.47	$1,995.93	$51.02

Stuttgart – Urumqi: Automotive, Demand 346, Rail rate $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$419.90		$419.90	$8.25	$2,087.63	$17.29	$6.63	$2,111.56	$41.50	$2,531.46	$49.75
727	$929.19	$1.93	$931.12	$18.30	$4,175.27	$13.13	$9.26	$4,197.66	$82.50	$5,128.77	$100.80
Rail	$679.13	$868.86	$1,547.99	$30.42	$144.46	$371.80	$267.64	$783.91	$15.41	$2,331.90	$45.83

Stuttgart – Urumqi: Automotive, Demand 750, Rail rate $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$910.19		$910.19	$8.25	$2,087.63	$37.48	$29.42	$2,154.53	$19.53	$3,064.72	$27.79
727	$2,014.14	$4.17	$2,018.32	$18.30	$4,175.27	$28.45	$42.63	$4,246.35	$38.50	$6,264.67	$56.80
Rail	$1,472.11	$868.86	$2,340.97	$21.22	$313.15	$805.93	$568.60	$1,687.67	$15.30	$4,028.64	$36.53

Stuttgart – Urumqi: Automotive, Demand 1000, Rail rate $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$1,213.59		$1,213.59	$8.25	$2,087.63	$49.97	$51.64	$2,189.24	$14.89	$3,402.83	$23.14
727	$2,685.53	$5.57	$2,691.09	$18.30	$4,175.27	$37.94	$75.45	$4,288.66	$29.16	$6,979.75	$47.46
Rail	$1,962.81	$868.86	$2,831.67	$19.26	$417.53	$1,074.57	$754.90	$2,247.00	$15.28	$5,078.66	$34.53

Stuttgart – Urumqi: Automotive, Demand 2500, Rail rate $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$3,033.96		$3,033.96	$8.25	$2,087.63	$124.93	$315.42	$2,527.98	$6.88	$5,561.94	$15.13
727	$6,713.81	$13.92	$6,727.73	$18.30	$4,175.27	$94.85	$467.97	$4,738.08	$12.89	$11,465.81	$31.19
Rail	$4,907.02	$868.86	$5,775.88	$15.71	$1,043.82	$2,686.43	$1,873.80	$5,604.04	$15.24	$11,379.92	$30.95

Stuttgart – Urumqi: Automotive, Demand 4000, Rail rate $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$4,854.34		$4,854.34	$8.25	$2,087.63	$199.88	$803.53	$3,091.05	$5.25	$7,945.39	$13.51
727	$10,742.10	$22.27	$10,764.37	$18.30	$4,175.27	$151.76	$1,196.24	$5,523.26	$9.39	$16,287.63	$27.69
Rail	$7,851.24	$868.86	$8,720.09	$14.82	$1,670.11	$4,298.28	$2,994.56	$8,962.95	$15.24	$17,683.05	$30.06

Stuttgart – Urumqi: Automotive, Demand 7500, Current rail rate											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$9,101.89		$9,101.89	$8.25	$2,087.63	$374.78	$2,824.28	$5,286.70	$4.79	$14,388.59	$13.05
727	$20,141.44	$41.75	$20,183.19	$18.30	$4,175.27	$284.55	$4,208.33	$8,668.15	$7.86	$28,851.33	$26.16
Rail	$14,721.07	$868.86	$15,589.93	$14.13	$3,131.45	$8,059.28	$5,616.92	$16,807.65	$15.24	$32,397.58	$29.37

Stuttgart – Urumqi: Automotive, Demand 10,000, Current rail rate											
	Transport: excl. truck	Total truck	Total Transport	Per Turbo	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Turbo	Total	Per Turbo
UCA	$12,135.86		$12,135.86	$8.25	$2,087.63	$499.71	$5,038.43	$7,625.77	$5.19	$19,761.63	$13.44
727	$26,855.25	$55.66	$26,910.92	$18.30	$4,175.27	$379.40	$7,496.25	$12,050.91	$8.19	$38,961.83	$26.49
Rail	$19,628.09	$868.86	$20,496.95	$13.94	$4,175.27	$10,745.70	$7,496.25	$22,417.22	$15.24	$42,914.17	$29.18

4.4.3 Shenzhen - Stuttgart: Laptops demand 290 – 10,000 kg

Shenzhen - Stuttgart: Laptops, Demand 290, Shipping rate $1000 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$578.63		$578.63	$5.85	$2,983.27	$28.99	$6.91	$3,019.17	$30.50	$3,597.80	$36.35
777	$400.04	$390.56	$790.60	$7.99	$173.03	$27.66	$551.69	$752.38	$7.60	$1,542.98	$15.59
777 +10	$400.04	$390.56	$790.60	$7.99	$173.03	$41.22	$551.69	$765.94	$7.74	$1,556.54	$15.73
727	$1,199.13	$2.15	$1,201.28	$12.14	$5,966.53	$21.87	$9.72	$5,998.12	$60.60	$7,199.40	$72.74
Ship	$57.01	$953.81	$1,010.81	$10.21	$173.03	$891.82	$335.01	$1,399.87	$14.14	$2,410.68	$24.36

Shenzhen - Stuttgart: Laptops, Demand 344, Shipping rate $1250 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$686.38		$686.38	$5.85	$2,983.27	$34.39	$9.72	$3,027.38	$25.79	$3,713.76	$31.63
777	$474.53	$390.56	$865.09	$7.37	$205.25	$32.81	$652.58	$890.64	$7.59	$1,755.73	$14.95
777 +10	$474.53	$390.56	$865.09	$7.37	$205.25	$48.89	$652.58	$906.72	$7.72	$1,771.81	$15.09
727	$1,422.42	$2.55	$1,424.96	$12.14	$5,966.53	$25.95	$13.61	$6,006.09	$51.16	$7,431.05	$63.29
Ship	$67.62	$953.81	$1,021.43	$8.70	$205.25	$1,057.89	$395.55	$1,658.69	$14.13	$2,680.11	$22.83

Shenzhen - Stuttgart: Laptops, Demand 427, Shipping rate $1500 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$851.99		$851.99	$5.85	$2,983.27	$42.69	$14.98	$3,040.94	$20.87	$3,892.92	$26.71
777	$589.02	$390.56	$979.58	$6.72	$254.77	$40.73	$807.68	$1,103.17	$7.57	$2,082.76	$14.29
777 +10	$589.02	$390.56	$979.58	$6.72	$254.77	$60.69	$807.68	$1,123.14	$7.71	$2,102.72	$14.43
727	$1,765.61	$3.16	$1,768.77	$12.14	$5,966.53	$32.21	$20.86	$6,019.61	$41.31	$7,788.37	$53.44
Ship	$83.94	$953.81	$1,037.74	$7.12	$254.77	$1,313.13	$488.61	$2,056.51	$14.11	$3,094.25	$21.23

Shenzhen - Stuttgart: Laptops, Demand 516, Shipping rate $1250 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$1,029.57		$1,029.57	$5.85	$2,983.27	$51.59	$21.88	$3,056.73	$17.36	$4,086.30	$23.20
777	$711.79	$390.56	$1,102.35	$6.26	$307.87	$49.21	$974.00	$1,331.09	$7.56	$2,433.44	$13.82
777 +10	$711.79	$390.56	$1,102.35	$6.26	$307.87	$73.34	$974.00	$1,355.21	$7.70	$2,457.57	$13.95
727	$2,133.62	$3.82	$2,137.44	$12.14	$5,966.53	$38.92	$30.36	$6,035.82	$34.27	$8,173.25	$46.41
Ship	$101.43	$953.81	$1,055.24	$5.99	$307.87	$1,586.83	$588.40	$2,483.11	$14.10	$3,538.35	$20.09

Shenzhen - Stuttgart: Laptops, Demand 641, Shipping rate $1500 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$1,278.98		$1,278.98	$5.85	$2,983.27	$64.08	$33.76	$3,081.11	$14.08	$4,360.09	$19.93
777	$884.22	$390.56	$1,274.78	$5.83	$382.45	$61.14	$1,207.65	$1,651.24	$7.55	$2,926.02	$13.37
777 +10	$884.22	$390.56	$1,274.78	$5.83	$382.45	$91.10	$1,207.65	$1,681.20	$7.68	$2,955.99	$13.51
727	$2,650.49	$4.74	$2,655.23	$12.14	$5,966.53	$48.35	$46.70	$6,061.59	$27.71	$8,716.80	$39.84
Ship	$126.01	$953.81	$1,079.81	$4.94	$382.45	$1,971.24	$728.59	$3,082.28	$14.09	$4,162.09	$19.02

Shenzhen - Stuttgart: Laptops, Demand 854, Shipping rate $1500 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$1,703.97		$1,703.97	$5.85	$2,983.27	$85.38	$59.93	$3,128.57	$10.73	$4,832.54	$16.58
777	$1,178.04	$390.56	$1,568.60	$5.38	$509.54	$81.45	$1,605.88	$2,196.87	$7.54	$3,765.47	$12.92
777 +10	$1,178.04	$390.56	$1,568.60	$5.38	$509.54	$121.38	$1,605.88	$2,236.80	$7.67	$3,805.40	$13.06
727	$3,531.23	$6.32	$3,537.55	$12.14	$5,966.53	$64.42	$82.63	$6,113.58	$20.98	$9,651.08	$33.11
Ship	$167.88	$953.81	$1,121.68	$3.85	$509.54	$2,626.27	$967.53	$4,103.34	$14.08	$5,225.02	$17.93

Shenzhen - Stuttgart: Laptops, Demand 1250, Shipping rate $1500 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$2,494.10		$2,494.10	$5.85	$2,983.27	$124.97	$128.39	$3,236.63	$7.59	$5,730.73	$13.43
777	$1,724.30	$390.56	$2,114.86	$4.96	$745.82	$119.22	$2,346.60	$3,211.64	$7.53	$5,326.50	$12.49
777 +10	$1,724.30	$390.56	$2,114.86	$4.96	$745.82	$177.66	$2,346.60	$3,270.08	$7.67	$5,384.94	$12.62
727	$5,168.66	$9.25	$5,177.91	$12.14	$5,966.53	$94.29	$176.50	$6,237.31	$14.62	$11,415.08	$26.76
Ship	$245.72	$953.81	$1,199.53	$2.81	$745.82	$3,844.07	$1,411.96	$6,001.85	$14.07	$7,201.38	$16.88

Shenzhen - Stuttgart: Laptops, Demand 2500, Shipping rate$1500 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$4,988.20		$4,988.20	$5.85	$2,983.27	$249.93	$513.60	$3,746.80	$4.39	$8,735.01	$10.24
777	$3,448.59	$390.56	$3,839.16	$4.50	$1,491.63	$238.44	$4,687.72	$6,417.80	$7.52	$10,256.96	$12.02
777 +10	$3,448.59	$390.56	$3,839.16	$4.50	$1,491.63	$355.32	$4,687.72	$6,534.68	$7.66	$10,373.84	$12.16
727	$10,337.32	$18.50	$10,355.82	$12.14	$5,966.53	$188.57	$704.16	$6,859.26	$8.04	$17,214.07	$20.17
Ship	$491.44	$953.81	$1,445.25	$1.69	$1,491.63	$7,688.14	$2,816.63	$11,996.41	$14.06	$13,441.66	$15.75

Shenzhen - Stuttgart: Laptops, Demand 4000, Shipping rate $1500 per TEU											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$7,981.13		$7,981.13	$5.85	$2,983.27	$399.89	$1,314.90	$4,698.06	$3.44	$12,679.19	$9.29
777	$5,517.75	$390.56	$5,908.32	$4.33	$2,386.61	$381.50	$7,503.03	$10,271.15	$7.52	$16,179.47	$11.85
777 +10	$5,517.75	$390.56	$5,908.32	$4.33	$2,386.61	$568.52	$7,503.03	$10,458.16	$7.66	$16,366.48	$11.99
727	$16,539.71	$29.60	$16,569.32	$12.14	$5,966.53	$301.71	$1,802.33	$8,070.57	$5.91	$24,636.56	$18.05
Ship	$786.31	$953.81	$1,740.11	$1.27	$2,386.61	12,301.03	$4,505.82	$19,193.46	$14.06	$20,933.57	$15.33

Shenzhen - Stuttgart: Laptops, Demand 7500, Current shipping rates											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$14,964.61		$14,964.61	$5.85	$2,983.27	$749.80	$4,623.31	$8,356.37	$3.26	$23,320.98	$9.11
777	$10,345.78	$390.56	$10,736.35	$4.19	$4,474.90	$715.32	$14,097.39	$19,287.61	$7.54	$30,023.96	$11.73
777 +10	$10,345.78	$390.56	$10,736.35	$4.19	$4,474.90	$1,065.97	$14,097.39	$19,638.26	$7.67	$30,374.61	$11.87
727	$31,011.96	$55.51	$31,067.47	$12.14	$5,966.53	$565.71	$6,346.82	$12,879.07	$5.03	$43,937.39	$17.16
Ship	$1,474.32	$953.81	$2,428.13	$0.95	$4,474.90	23,064.43	$8,462.43	$36,001.76	$14.06	$38,429.89	$15.01

Shenzhen - Stuttgart: Laptops, Demand 10000, Current shipping rates											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$19,952.81		$19,952.81	$5.85	$2,983.27	$999.74	$8,219.98	$12,202.99	$3.58	$32,155.80	$9.42
777	$13,794.38	$390.56	$14,184.94	$4.16	$5,966.53	$953.76	$18,829.33	$25,749.63	$7.54	$39,934.57	$11.70
777 +10	$13,794.38	$390.56	$14,184.94	$4.16	$5,966.53	$1,421.29	$18,829.33	$26,217.16	$7.68	$40,402.10	$11.84
727	$41,349.28	$74.01	$41,423.29	$12.14	$5,966.53	$754.28	$11,301.60	$18,022.41	$5.28	$59,445.71	$17.42
Ship	$1,965.76	$953.81	$2,919.57	$0.86	$5,966.53	30,752.57	$11,301.60	$48,020.70	$14.07	$50,940.27	$14.93

4.4.4 Urumqi – Stuttgart: Laptops demand 50 – 10,000 kg

Urumqi - Stuttgart: Laptops, Demand 50, Rail $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$60.68		$60.68	$3.56	$2,983.27	$3.48	$0.29	$2,987.03	$175.04	$3,047.71	$178.60
727	$134.28	$0.28	$134.55	$7.88	$5,966.53	$2.64	$0.29	$5,969.47	$349.81	$6,104.02	$357.70
Rail	$98.14	$868.86	$967.00	$56.67	$29.83	$74.82	$57.90	$162.55	$9.53	$1,129.55	$66.19

Urumqi - Stuttgart: Laptops, Demand 75 Rail $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$91.02		$91.02	$3.56	$2,983.27	$5.22	$0.57	$2,989.06	$116.77	$3,080.08	$120.33
727	$201.41	$0.42	$201.83	$7.88	$5,966.53	$3.96	$0.65	$5,971.15	$233.27	$6,172.98	$241.16
Rail	$147.21	$868.86	$1,016.07	$39.69	$44.75	$112.22	$86.85	$243.83	$9.53	$1,259.90	$49.22

Urumqi - Stuttgart: Laptops, Demand 100, Rail $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$121.36		$121.36	$3.56	$2,983.27	$6.96	$0.95	$2,991.17	$87.64	$3,112.53	$91.20
727	$268.55	$0.56	$269.11	$7.88	$5,966.53	$5.28	$1.16	$5,972.98	$175.01	$6,242.08	$182.89
Rail	$196.28	$868.86	$1,065.14	$31.21	$59.67	$149.63	$115.81	$325.10	$9.53	$1,390.24	$40.73

Urumqi - Stuttgart: Laptops, Demand 200, Rail $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$242.72		$242.72	$3.56	$2,983.27	$13.92	$3.39	$3,000.57	$43.96	$3,243.29	$47.51
727	$537.11	$1.11	$538.22	$7.88	$5,966.53	$10.57	$4.63	$5,981.73	$87.63	$6,519.95	$95.52
Rail	$392.56	$868.86	$1,261.42	$18.48	$119.33	$299.27	$231.61	$650.21	$9.53	$1,911.63	$28.01

Urumqi - Stuttgart: Laptops, Demand 500, Rail $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$606.79		$606.79	$3.56	$2,983.27	$34.79	$19.68	$3,037.73	$17.80	$3,644.53	$21.36
727	$1,342.76	$2.78	$1,345.55	$7.88	$5,966.53	$26.42	$28.95	$6,021.90	$35.29	$7,367.44	$43.17
Rail	$981.40	$868.86	$1,850.26	$10.84	$298.33	$748.16	$579.03	$1,625.52	$9.53	$3,475.79	$20.37

Urumqi - Stuttgart: Laptops, Demand 1000, Rail $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$1,213.59		$1,213.59	$3.56	$2,983.27	$69.58	$76.71	$3,129.56	$9.17	$4,343.15	$12.73
727	$2,685.53	$5.57	$2,691.09	$7.88	$5,966.53	$52.83	$115.79	$6,135.15	$17.98	$8,826.24	$25.86
Rail	$1,962.81	$868.86	$2,831.67	$8.30	$596.65	$1,496.33	$1,158.07	$3,251.05	$9.53	$6,082.72	$17.82

Urumqi - Stuttgart: Laptops, Demand 2500, Rail $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$3,033.96		$3,033.96	$3.56	$2,983.27	$173.96	$472.32	$3,629.55	$4.25	$6,663.51	$7.81
727	$6,713.81	$13.92	$6,727.73	$7.88	$5,966.53	$132.08	$723.68	$6,822.29	$8.00	$13,550.02	$15.88
Rail	$4,907.02	$868.86	$5,775.88	$6.77	$1,491.63	$3,740.82	$2,895.17	$8,127.62	$9.53	$13,903.51	$16.29

Urumqi - Stuttgart: Laptops, Demand 4000, Rail $0.60											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$4,854.34		$4,854.34	$3.56	$2,983.27	$278.34	$1,206.14	$4,467.75	$3.27	$9,322.09	$6.83
727	$10,742.10	$22.27	$10,764.37	$7.88	$5,966.53	$211.32	$1,852.68	$8,030.54	$5.88	$18,794.91	$13.77
Rail	$7,851.24	$868.86	$8,720.09	$6.39	$2,386.61	$5,985.32	$4,632.27	$13,004.20	$9.53	$21,724.29	$15.91

Urumqi - Stuttgart: Laptops, Demand 7500, Rail $0.70											
	Transport: excl. truck	Total truck	Total Transport	Per Laptop	Total warehouse	Inventory transit	Total handling	Total Cargo	Per Laptop	Total	Per Laptop
UCA	$9,101.89		$9,101.89	$3.56	$2,983.27	$521.88	$4,253.42	$7,758.56	$3.03	$16,860.46	$6.59
727	$20,141.44	$41.75	$20,183.19	$7.88	$5,966.53	$396.23	$6,513.80	$12,876.56	$5.03	$33,059.75	$12.92
Rail	$14,721.07	$868.86	$15,589.93	$6.09	$4,474.90	$11,222.47	$8,685.50	$24,382.87	$9.53	$39,972.80	$15.62

Urumqi - Stuttgart: Laptops, Demand 10000, Rail $0.70											
	Transport: excl. truck	**Total truck**	**Total Transport**	**Per Laptop**	**Total warehouse**	**Inventory transit**	**Total handling**	**Total Cargo**	**Per Laptop**	**Total**	**Per Laptop**
UCA	$12,135.86		$12,135.86	$3.56	$2,983.27	$695.84	$7,605.57	$11,284.67	$3.31	$23,420.53	$6.86
727	$26,855.25	$55.66	$26,910.92	$7.88	$5,966.53	$528.31	$11,580.66	$18,075.51	$5.30	$44,986.42	$13.18
Rail	$19,628.09	$868.86	$20,496.95	$6.01	$5,966.53	$14,963.30	$11,580.66	$32,510.50	$9.53	$53,007.45	$15.53

Appendix 5 – Pictures

ATLAS concept, PUCA

Singular Flyox I Amphibious UAV *under development*

Bluebird Electric, PUCA

Dorsal Aircraft Corporation