The first step towards sizes for modular standard containers for the Physical Internet

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1 Abstract

An attempt was made to develop a method for determining the sizes of PI-containers. One starts with the sizes of actual shipments and bases the sizes of containers on these. The other takes sizes from containers and takes fractions of this to make the container easier to combine. Four steps were proposed. The first is determining the sizes of the container, the second is to find the right container to fit the shipment, the third is to calculate the space left over and the last is to compare the different sizes and see which one is the best. The main conclusion derived from the research is that a higher variety of sizes leads to a better fit and less space wasted. This would however make the combining of a full size container more difficult.
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2 Introduction

Logistics is one of the most important aspects in the modern day economy. The Physical internet (PI) is a revolutionary new way of thinking about logistics. Montreuil et al. (2013) describes the Physical Internet as “An open global logistics system founded on physical, digital and operational inter connectivity through encapsulation, interfaces and protocols”. The components of the Physical Internet are depicted in Figure 1. The Physical Internet makes use of modular standard containers. This means all the containers comply to standard sizes, which makes it easier to use and handle in practice. This way, the Physical Internet can be a standardized system which is more efficient. However, the sizes for modular standard containers are yet to be determined.

The current day logistics lack in efficiency. Montreuil (2011) describes thirteen problems with logistics as they are now. Several involve the problem with the container and its transport. It is stated that at the moment, a lot of the containers that are shipped, are filled with air and the packaging of the goods. This means there is more space wasted on air and the plastics holding it together than on the actual products. Also, there is too much empty travel, meaning that the transport gets emptier and emptier when transporting, which results in traveling with an empty container. To tackle this problem, a standard set of sizes has to be developed. Montreuil et al. (2010) propose modular dimensions of 0.12, 0.24, 0.36, 0.48, 0.6, 1.2, 2.4, 3.6, 4.8, 6 and 12 meters. Meller et al. (2012) uses different dimensions, with the smallest being 0.2 meters and the biggest being 2.4 meters.

However, the actual sizes of PI-containers are yet to be determined. This is needed, since the Physical Internet can not exist without a modular standard for its containers. In the literature, there is not much written regarding the way of determining what sizes are optimal for PI-containers. As stated before, there are sizes proposed, but none are examined to be the most optimal in practice. Therefore, a way to determine the optimal sizes needs to be developed.

The focus of this thesis will lie on getting a clear view of shipments and how this will fit inside different dimensions of containers. To see how this happens, the following research question is formulated:

- **Research question**: How can a set of sizes for modular standard containers for the Physical Internet be determined?
For this question to be answered, two methods will be evaluated. One where the sizes are picked from the obtained data. This will serve as the base for deriving the dimensions needed for containers. For the second method, the container of 6 by 2.4 by 2.4 meters will be taken as a starting point. From here, these dimensions will be cut in even pieces to get a more standardized container. The goal is to find the best method for determining the sizes and eventually find a first cut towards standardized modular containers for the Physical Internet.

This thesis will be made up of several parts. The first part will be the theoretical background, reviewing literature regarding this topic. The second part will be the methodology that is designed to find the right fit for shipments within several sizes for potential containers. The third part is the analysis in which the proposed methods will be executed using real life data. In the fourth part, the analysed data will be discussed and in the last part several conclusions will be drawn from the discussion.
3 Theoretical background

Three topics from the literature were reviewed. The first involves the current container requirements. This way, it can be seen which conditions exist for current containers, which might also be required for the PI-containers. In the second part, the current literature regarding PI-containers is reviewed. Lastly, the shipping concept is reviewed.

3.1 Current container requirements

In literature, there are several constraints when packing a container, mostly described in a Container Loading Problem (CLP). There are several formulas for determining how to pack a container. The base for the articles surrounding CLP is Chen et al. (1995). In this article, they propose a formula to minimize space left inside a 3d container. Pisinger (2002) describes four types of container loading problems: strip packing, bin-packing, multi-container loading and knapsack loading, while focusing on the latter. An algorithm was developed, again with the goal to reduce the space left within a container.

Junquiera et al. (2012) describe CLP with additional stability and load bearing constraints. Gendreau et al. (2006) combined CLP with a routing problem. Besides focusing on the routing, they also stated some other constraints. These additional constraints are the weight and packing constraint, the fragility of shipped goods and the ease of unloading. Bischoff et al. (1995) points out several other constraints. These constraints are orientation constraints, load bearing strength of items, handling constraints, load stability, grouping of items, multi-drop locations, separation of items within a container, complete shipment of certain item goods, shipment priorities, complexity of the loading arrangement, container weight limit and weight distribution within a container. Besides all the aforementioned constraints, Gehring (1997) takes in mind the balance constraint.

Since the PI container will be standardized, to make sure every container has a fit, certain standards have to be met. Recent work by Martin et al. (2018) compared the ISO (International Organization for Standardization) regulations with those of the CSC (Convention for Safe Containers) constructed by the IMO (International Maritime Organisation). The strength of the walls, the strength of the floor, the strength for the lifting and the strength for stacking were named as aspects of a container that need regulations.

Despite a container needing these constraints, these will not be taken into account for coming up with a sizing for PI-containers. However, it is still important to keep these in mind for the design. The main idea of minimizing the amount of space left inside a container will serve as a base for the determination of sizes for the PI-containers.
3.2 PI container sizes

The PI-container has several other needs as well. Sallez et al. (2015) described seven aspects that a PI-container should contain. First, it must come in multiple sizes. Second, it must be easy to use in practice. Third, it should be made of material that does not harm the environment. Fourth, minimize the amount of packaging used. Fifth, it should come in various usage-adapted structural grades. Sixth, it should be able to pack products with certain requirements. Lastly, the containers need to be able to be sealed.

Sallez et al. (2016) describes the functions of the PI-containers. These functions are transport, packaging and handling. The T-container for transport has a proposed length of 1.2 m, 2.4 m, 3.6 m, 4.8 m, 6 m or 12 m. The width and height are 1.2 m or 2.4 m. The handling containers are stackable to at least 2.4m.

The concept of T-containers, H-containers and P-containers, as the containers for transport, handling and packaging are called, is also explained by Montreuil et al. (2015). The transport and handling containers are to be the same sizes, whereas the packaging containers need smaller sizes, since they will be the substitute of carton shipping boxes for example.

The main components of the Physical Internet containers are depicted in Figure 3. Lin et al. (2014) went in on the composition of standardised modular containers and acknowledge the need for it in PI. A couple of benefits to PI-containers are stated. First, there will be less effort needed to design containers, since they will all be standardized. Second, there will be economies of scale. Third, the number of purchasing agents and testing requirement decrease, since there is a lower variety of container sizes. Lastly, there will be less emissions with fewer container sizes.

Tran-Dang et al. (2017) describe the need for sensors in the PI container and stated four conditions that a PI-container has to meet. The first constraint is that the PI-container is stackable. This means multiple smaller containers should be able to be compiled in one modular standard container. This can be seen in Figure 2, derived from Montreuil et al. (2010). The second constraint is that the PI-containers must be aligned. The combined container must meet the standard sizes for a full PI container. The third constraint is the prohibition of overlap between containers, since they can not be stacked into each other. The last constraint is that the PI-container does not harm the connection between the other containers.
3.3 Shipment

The shipment size literature has a close bond with freight transportation mode and the relationship between shippers and carriers. Holguin-Veras et al. (2009) consider three agents that are important in freight demand. These are the shippers, the carriers and the receivers. These have three types of interactions. One way interaction in which the shipper decides the mode of transport, two way in which the shipper and carrier influence the mode of transport and no interaction, in which the carrier makes the decision. The shipment size is named as the most important aspect in the relation between the shippers and the carriers. The shipment size helps to determine the mode of transport, while the mode of transport influences the shipment size as well.

The shipment will thus determine the mode of transport as well as the other way around. Besides the mode of transport, the shipment will have to comply to other constraints as well. Dowsland and Dowsland (1992) describe several packing problems. These packing problems involve the loading problem for pallets, as well as bin packing. Terno et al. (2000) take into account several conditions when formulating a multi pallet loading problem. These conditions are the weight condition, placement condition, splitting condition, connectivity condition and stability condition. In other words, the load that is on the pallet may not exceed a certain weight limit, some items are not supposed to be stacked on top of each other, a full order must be on one pallet when possible, items must be loaded without interruption and the pallet should be stable for transport.

As stated before, Montreuil et al. (2015) consider the packaging for transport
and wants to substitute it for the p-containers. The layers of packaging he described are visible in figure 4. Oostendorp et al. (2006) described the primary functions of packaging. These are protection of the product, ability to distribute the package and for the packaging to make clear to stakeholders what is inside the packaging. There are also several levels of packaging. The primary packaging is the packaging immediately on the product, the secondary packaging is the packaging of the primary packaging and the tertiary packaging is the packaging for transport.

So the shippers, carriers and receivers will see a difference, since the sizes and ways of handling might change. The way of packaging an item for shipment might change, since it will now be put in p-containers. The packaging might still need to stay within the limits of the constraints.
4 Methodology

The goal of this research is to create a method for determining optimal PI-container sizes and ultimately come with a solution for the first cut in a regular container.

4.1 Research design

For the research design, a quantitative data analysis will be performed. There will be two methods. One where the sizes will be based on the data and one where the sizes will be determined beforehand by dividing a standard container in equally big sizes. The Physical Internet makes use of combined containers, for this research it is assumed that a full size (combined) container will be 6 by 2.4 by 2.4 meters.

For both methods determining the sizes, the term "cut" will be used frequently. When a container is divided in two parts, it has had just one cut in the middle. So one cut means that the container is divided in two pieces, two cuts means it is divided in three pieces and so on. To get a view of the amount of cuts that have to be made, data involving the height, width and depth of shipments needs to be analysed.

For the first method, the data of the sizes of shipments will determine the size of a container. The method will try to find a cut for the 6 meters side. The sizes can have a high variety and not have ideal sizes for combining in a full size container.

The second method takes the full size standard container as a starting point. The question is, will the length of 6 meters change to 3, to 2, to 1.5 or 1.2 meters or will another length be more optimal? This will be analysed by looking at the collected data. The best fit needs to be found to facilitate a new mode of logistics. This can also be done for other dimensions. It will be seen whether the side of 2.4 meters needs to change to 1.2, 0.8 or 0.6 meters. It will also be seen what happens when more variety is added. For example, when a container of 1.2 by 2.4 by 2.4 meters is combined with one of 3 and 1.8. This should be possible, as long as the combined container is 6 by 2.4 by 2.4 meters.

4.2 Data collection

The data that needs to be collected are the dimensions of the shipments. This means the height, width and depth of the shipments have to be collected. With help of this data, the optimal dimensions for a PI-container can be calculated. This will be done by looking at different sets of sizes. The best size is determined by looking at the amount of space left in a container. This data will be collected at a possible future hub for the PI, in this case, a distribution centre. The data collected will be primary data, since this will be collected by the researcher.

The dimensions of 50 different shipments were measured at a distribution centre holding gardening products, as well as furniture items. Every of the 50 instances had different dimensions.
4.3 Data measurements

The data was measured by hand. This data will be put in a worksheet to be able to analyse it.

4.4 Analysis method

The analysis will fit the shipments in the proposed set of sizes. The space leftover will be reduced to a minimum. The one with the least amount of space left will be considered to be the best. This will be done with the use of two methods, as mentioned before.

4.4.1 Frequency

With the term frequency, the amount of sizes fitting a certain interval is meant. The frequency part considers sizes that are not standard, meaning they can not necessarily be compiled in a combined container. The sizes chosen are the intervals where the most observations lie between. The sizes for the containers will thus be determined by the sizes of the shipments.

**Step 1: Determining the sizes**

For the development of the sizes of the container, first it will be analysed what the best sets of sizes will be based on the data. This will be done by putting the observations within certain intervals. The interval with the highest occurrence will be considered. The higher bound of the interval will be taken as one of the container sizes. This will be done several times, until there is a set of sizes.

**Step 2: Determine which container has the right fit for the shipment**

Now that the sizes of the PI containers are determined, it should be looked at whether the observations will fit within this type of container. The first step is looking whether the shipment fits the smallest proposed size. If this is not the case, try to fit it in the next container size that would be the smallest after the first one. This process will be repeated until all the shipments fit within the smallest container possible given its dimensions.

**Step 3: Calculate the space left within the container**

The shipments are all divided over the proposed container sizes now. Now, the amount of empty space will be calculated. This is simply done by subtracting the size of shipment from the total container size. The one with the least amount of empty spaced would be considered to be the more optimal size.

**Step 4: Determine the best option**
Compare the results of all the proposed sets of sizes. The one with the least amount of space left would be considered optimal given the data available.

4.4.2 Standard Sizes

Standard sizes are the earlier mentioned sizes that are made up out of a standard container that is assumed to be 6 by 2.4 by 2.4. For the side of 6 meters this means that the size will be either 3, 2, 1.5 or 1.2 meters for the first cut that will be made. These are all fractions of 6, making them more ideal for a combined container. The sizes mentioned earlier are just for the first cut. This means that the container will be cut in 2, 3, 4 or 5 pieces. This is applicable for the height and depth as well (assuming that the length is the side of 6 meters).

Step 1: Determining the sizes

First, the amount of cuts has to be determined for each dimension. For the first cut, two dimensions are already known, these are 240x240 centimeters. It is first analysed whether the shipments would fit in the proposed sizes.

Step 2: Determine which container has the right fit for the shipment

A fit with the standard sizes needs to be found to make sure whether a shipment fits the proposed containers. first it is analysed with the assumption that if a shipment will not fit the proposed standard size container, it will have to be put into a full sized container. Later there are also other sizes of container analysed, with sizes that, when combined, add up to a total of six meters.

Step 3: Calculate the space left within the container

Just like in the Frequency part, the amount of empty space within a container will be calculated.

Step 4: Determine the best option

Compare the results. See which one of the proposed container sizes leaves the least amount of space unused.
5 Analysis

As said before, the data was obtained from a distribution centre. At this centre there were three types of loads, pallet, colli and special delivery. The special delivery contained packages that could not go on the pallet or colli, for example toy slides for in the garden. The data obtained and analysed were for the biggest part colli loads.

5.1 Fit with most frequent sizes

To find the best option for sizes, the four steps mentioned in the previous section were followed. The first step is to determine the sizes of the containers.

In the figures above, the widths, depths and heights of the observed shipments are summarized. The most observations were between the 1.2 and 1.3 meters for the widths, between 0.8 and 0.9 meters for the depth and between 1.8 and 2 meters for the height. With the help of this data, the possible sizes were determined. Two sets of sizes were chosen. The first set took steps of 20cm. To be able to fit all the dimensions of the shipment, the range that was chosen was from 0.8 to 1.8 meters, with steps of 0.2 meters between them. The second had three sizes of 0.9, 1.2 and 1.8 meters.

The next step is to assign the shipments to the sizes in the set. This is done for both the chosen sets of sizes. As can be seen in table 1, almost all product
Table 1: The amount of items fitting the containers for the changed length

<table>
<thead>
<tr>
<th>Size of the length (cm)</th>
<th>Amount of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>21</td>
</tr>
<tr>
<td>100</td>
<td>23</td>
</tr>
<tr>
<td>120</td>
<td>5</td>
</tr>
<tr>
<td>140</td>
<td>1</td>
</tr>
<tr>
<td>160</td>
<td>0</td>
</tr>
<tr>
<td>180</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>50</strong></td>
</tr>
</tbody>
</table>

were able to fit within the first two instances. Reason for this is that the depth
and width are interchangeable. The height is one that will not be fitted in the
depth or width, since the height is determined by the loading on a pallet and
might need some stability or fragility constraint. Note that there are very little
observations. When the amount of observations would have been higher, the
distribution over the different sizes could have been different.

Table 2: The amount of items fitting the containers for the changed length

<table>
<thead>
<tr>
<th>Size of the length (cm)</th>
<th>Amount of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>35</td>
</tr>
<tr>
<td>120</td>
<td>14</td>
</tr>
<tr>
<td>180</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>50</strong></td>
</tr>
</tbody>
</table>

Table 2 presents the second set of sizes chosen from the data. In table 2,
most products are already able to fit within the containers with a length of 90
cm. There is only one item that would not fit within a container with a size
of 120 cm. Since there is only one bigger size, it has to use a container with
a length of 180 cm, since there are no sizes that are small enough to fit it.
However, this was able in the previous case, where such an item would be put
in a container with a length of 140 cm. Now, the third step, the calculation of
the space left in the container, will be performed.

Table 3: The amount of space leftover for the given sets of sizes

<table>
<thead>
<tr>
<th>Sizes</th>
<th>Empty space (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steps of 20</td>
<td>195.399.077</td>
</tr>
<tr>
<td>90, 120 and 180</td>
<td>212.103.077</td>
</tr>
</tbody>
</table>

In Table 3, the results of the calculations of space left within a container
are presented. The one with more different options and sizes has a considerable
smaller amount of empty space when all the products would be put into the
containers. Since the most important criterion is the amount of space left within a container, the first proposed set of container sizes would thus be preferred over the second.

5.2 Equal parts

In this part, the analysis of standard cuts is performed. This means that the size of 6 meters is cut up in lengths of 3, 2, 1.5 and 1.2 meters. Below, the amount of cuts and its dimensions are presented.

<table>
<thead>
<tr>
<th>Amount of Cuts</th>
<th>Dimensions of the separate container(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300x240x240</td>
</tr>
<tr>
<td>2</td>
<td>200x240x240</td>
</tr>
<tr>
<td>3</td>
<td>150x240x240</td>
</tr>
<tr>
<td>4</td>
<td>120x240x240</td>
</tr>
</tbody>
</table>

Table 4: The dimensions for a given amount of cuts

The same will be done for this part as was done in the previous part. The sizes are determined, as can be seen in Table 4. Next, the different shipments should be distributed over the different containers.

5.2.1 First cut

![Amount of shipments fitting the cuts](image)

Figure 9: The amount of items fitting for the first cut

As can be seen in the graph above, all of the observations were able to fit in
the first three sizes. Only one was not able to fit into a container with a length of 1.2 meters. Again, as was stated in the previous part, when the data set had more than 50 observations, this would probably have been more distributed. The assumption in this part is made that if a shipment does not fit within a small sized container, it is immediately placed in a full size container.

<table>
<thead>
<tr>
<th>Dimensions(cm)</th>
<th>Empty space (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300x240x240</td>
<td>787.527.077</td>
</tr>
<tr>
<td>200x240x240</td>
<td>499.527.077</td>
</tr>
<tr>
<td>150x240x240</td>
<td>355.527.077</td>
</tr>
<tr>
<td>120x240x240</td>
<td>296.775.077</td>
</tr>
</tbody>
</table>

Table 5: Amount of space left for the given dimensions

The smallest container would leave the least amount of space unused. However, there was one item that would not fit the proposed sizes. This item would be placed within a container of 600x240x240 cm. This one item makes up 10.65 percent of the total space left within the container. On average, this would only have to happen to four out of the 50 items in the dataset.

### 5.2.2 Second cut

Since the data is limited and did not really show the impact for the first cut. An attempt is made to use this method to determine the second cut. For the second cut, the size of 150x240x240 cm is assumed for the first cut. Again it is assumed in this part that when one part does not fit into the proposed cut, it needs a full bigger container. In this case a container of 150x240x240 cm.

<table>
<thead>
<tr>
<th>Amount of Cuts</th>
<th>Dimensions of the separate container(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120x150x240</td>
</tr>
<tr>
<td>2</td>
<td>80x150x240</td>
</tr>
<tr>
<td>3</td>
<td>60x150x240</td>
</tr>
<tr>
<td>4</td>
<td>48x150x240</td>
</tr>
</tbody>
</table>

Table 6: The dimensions for an amount of cuts

To get a better view of what the sizes would be, table 6 is generated. The dimension of 150cm represents the first cut in the length of 6 meters. the 120, 80, 60 and 48 centimeters are the cuts of the side that is 240 cm.

In the Figure 10, the amount of items fitting within the sizes for the second cut are shown. A little less than half the products will fit in a container of 80x150x240 cm. The container of 0.48 is left out of this analysis, since the amount of items fitting in is such a small amount that this will not be an ideal fit for the shipments.

Again, the amount of space left is calculated and compared. This can be seen in Table 7. The best size would be one of 120 centimeters, since this would
Figure 10: The amount of items fitting for the Second cut

<table>
<thead>
<tr>
<th>Dimensions(cm)</th>
<th>Empty space (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120x150x240</td>
<td>161.127.077</td>
</tr>
<tr>
<td>80x150x240</td>
<td>234.567.077</td>
</tr>
<tr>
<td>60x150x240</td>
<td>336.087.077</td>
</tr>
<tr>
<td>48x150x240</td>
<td>341.703.077</td>
</tr>
</tbody>
</table>

Table 7: Amount of space left for the given dimensions

leave the smallest amount of space. However, this is when it is assumed that there are no other sizes between the 80, 60 or 48 and 240 centimeters.

5.2.3 Equal parts with more variety

The amount of sizes will most likely not as limited as in the previous section. Therefore it is also analysed what would happen if there are sizes between the 240 and 120, 80, 60 or 48 centimeter size container. This is only possible if those sides of the container add up to a total of 240 centimeters. This means that the set of sizes of a container of 80x150x240 centimeters also offers a container of 160x150x240. So, when the shipment would not fit within a container with a length of 0.8 meters, it is put in one with a length of 1.6 meters. For the container of 60x150x240 centimeters, this means when a shipment does not fit, it can be placed in a container of 120x150x240 centimeters.

The first step was again to determine sizes. The sizes and the fit are both shown in the tables 8 to 11, summarizing the first two steps. This creates four sets of sizes.
<table>
<thead>
<tr>
<th>Size of the depth (cm)</th>
<th>Amount fitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>45</td>
</tr>
<tr>
<td>240</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 8: The set of sizes for one cut

<table>
<thead>
<tr>
<th>Size of the depth (cm)</th>
<th>Amount fitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>21</td>
</tr>
<tr>
<td>160</td>
<td>26</td>
</tr>
<tr>
<td>240</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 9: The set of sizes for two cuts

<table>
<thead>
<tr>
<th>Size of the depth (cm)</th>
<th>Amount fitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>4</td>
</tr>
<tr>
<td>120</td>
<td>43</td>
</tr>
<tr>
<td>180</td>
<td>3</td>
</tr>
<tr>
<td>240</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 10: The set of sizes for three cuts

<table>
<thead>
<tr>
<th>Size of the depth (cm)</th>
<th>Amount fitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>2</td>
</tr>
<tr>
<td>96</td>
<td>36</td>
</tr>
<tr>
<td>144</td>
<td>9</td>
</tr>
<tr>
<td>192</td>
<td>3</td>
</tr>
<tr>
<td>240</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 11: The set of sizes for four cuts

<table>
<thead>
<tr>
<th>Dimensions(cm)</th>
<th>Empty space (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120x150x240</td>
<td>161,127,077</td>
</tr>
<tr>
<td>80x150x240</td>
<td>159,687,077</td>
</tr>
<tr>
<td>60x150x240</td>
<td>141,687,077</td>
</tr>
<tr>
<td>48x150x240</td>
<td>118,791,077</td>
</tr>
</tbody>
</table>

Table 12: Amount of space left for the given dimensions

The space left within the containers is calculated. As can be seen in table 12, the amount of space left reduces drastically when offering a higher range of container sizes.
5.3 Impact of more variety in sizes

To get a better view of the effect of adding more variety in sizes within a set, different sets of sizes were chosen for the dimension of 48x150x240. Reason for this is that it allows for more different sizes. Since the side of 48cm is a fraction of 1/5 of 240cm, also sizes of 2/5, 3/5 and 4/5 are possible to complete the separate containers in one full container. When this analysis would be done with the size of 1/3 and 2/3, there is to few variety to conduct a decent analysis. The set of sizes used, is the one presented in Table 11.

<table>
<thead>
<tr>
<th>Amount of sizes</th>
<th>Dimensions of the biggest size (cm)</th>
<th>Empty space (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>48x150x240</td>
<td>341.703.077</td>
</tr>
<tr>
<td>3</td>
<td>96x150x240</td>
<td>155.079.077</td>
</tr>
<tr>
<td>4</td>
<td>144x150x240</td>
<td>123.975.077</td>
</tr>
<tr>
<td>5</td>
<td>192x150x240</td>
<td>118.791.077</td>
</tr>
</tbody>
</table>

Table 13: Amount of space left for the given dimensions

In table 13, the amount of sizes for 2 knew the sizes of 48x150x240 and 150x240x240cm. The one with 3 sizes had sizes of 48x150x240, 96x150x240cm and 150x240x240cm and so on. This shows that an increase in variety, leads to a decrease in empty space.
6 Discussion

There are several things that need to be discussed following the discussion. First, the methods will be compared. Next, the trade-offs that need to be considered will be discussed. After, other considerations will be discussed.

6.1 Comparison of methods

Both methods offered an option for determining the sizes of PI-containers. The main benefit of the first method is that it offers sizes that are based on the shipments, which results in a better fit and thus less unused space within the containers. This is different for the method that has a standard that starts with a container instead of the packaging. In this method the smaller containers were always even fractions of the container of 6 meters. The amount of empty space using this method was higher than the amount empty space using the first method.

However, the second method is a better method when looking at combining separate container in a full sized one. This will be difficult for the set of sizes that were established in the first method. When steps of 20 centimeters were used, there are more options to fit the shipments in, but it is hard to be able to fit a container with a dimension of 1.8 meter in a combined container with a size of 6. More specific sizes would be needed than when the standard is established by taking fractions of the 6 meter containers. When a 1.8 meter container is used, the other sizes should be fractions building up to a combined 4.2 meters.

6.2 Comparison within the standard method

By taking fractions there were two options for the shipments that did not fit within the containers. They were either to put the shipment into a full container or to create other sizes that still enable the separate containers to combine in a full container. When the full containers are used, this leaves a lot of empty space which is wasted. This can be seen in the analysis, where one shipment is accountable for 10.65 percent of the total amount of space wasted. The addition of extra container sizes to make the fit with the proposed containers possible reduces the empty space. This creates the problem that some products might need to lay in the hub longer, since there is a more specific size needed to complete the combined container. Solution to this problem might be to add an empty container, which also creates more unused space and thus waste.

Exception to this is the creation of containers that are fractions related to the power of two. These are always able to compile into a container of 600x240x240 cm. This can be seen in the analysis for containers with dimensions of 150x240x240 cm for the first cut and the one with dimensions of 60x150x240 cm for the second cut. So when a container of 300x240x240 cm is needed, there can also be two containers of 150x240x240 cm or eight of the 60x150x240 cm containers.
6.3 Trade-offs

There is a trade-off between smallest size for the best fit and slightly bigger sizes to make sure there is less empty travel. As said before, a container can not stay in the hub forever. This problem calls for the need of empty containers to complete a combined container to be 600x240x240 cm. However, this causes extra empty travel and thus extra waste. As can be seen in the analysis, with the smaller sizes, there is a better fit. However, when one shipment would not fit, it is placed in a much bigger container, which leads to more empty travel.

There is also a trade-off between amount of sizes and ease of combining. When there are fewer sizes, the products are more likely to fit. However, there will be more space left. When there are more sizes, the space will be reduced more, but it will be harder to find a right fit for the transportation of the combined container. This is where the problem for the hubs comes forward. In the literature, the relation between the shipper and carrier is described. The shippers are most likely to want more sizes, whereas the hub owners might want fewer sizes, to make it easier to combine a container at the hub.

One thing to consider to tackle the problem of combining separate containers into full containers is to make all dimension of the PI-containers into fractions of two, like said before. This way, the combined container will always be able to be combined into a full container. This does not apply to fractions of 3 or 5, since these need more specific sizes to fit into a combined container.

6.4 Other considerations

Besides the normal standard containers, there are several aspects that need to be taken into account for the PI-containers.

6.4.1 Latching

One of the most important aspects of a PI-container is that it has the ability to be latched into one combined container. The latch will be on every corner of the separate PI-boxes. For the latching to be possible, a box will need to have holes as well as a "hook" that is able to both extract as well as retreat into the box to make sure the combined container stays together. To make sure the latch can be extracted to all three sides (left/right, above/below and behind/in front) the latch would have to be placed more inside the PI-container, which would take up space as well.

Another option would be to put magnetic plates or some mechanism that works similar on the sides of the box, which would take up less space within the container.

To make sure the latching at the hub is possible, the PI-containers should have a system to identify the separate container within the combined container. Tran-Dang et al. (2017) wrote about the traceability of a container in the system. In their research, they assume that every corner has a sensor, in which information is stored. The information stored helps to identify its position within a combined PI-container.
6.4.2 Aviation

For the aviation containers, containers that are able to go into an airplane, the material of containers should be as light as possible so this does not limit the amount that can go into a plane. Right now, there are 16 different sizes for aviation containers, or unit load devices, as they are called. The sizes of these containers range from 114.3 cm to 162.6 cm for height, from 153.4 cm to 243.8 cm for depth, 156.2 cm to 317.5 cm for base width and from 156.2 to 472.4 for total width. Since the unit load devices have a different shape than a normal container, the combined container will have to be reassembled before entering a plane. An example of a current unit load device is presented in Figure 11.

6.4.3 Package lockers

For the distribution of smaller items, like parcel delivery, there could be a hub at a central point. At the moment there are already such systems that exist. The main idea is to create it in the same way as package lockers in apartment buildings. For this, each separate inhabitant has a locker with a code or a key. This could also be possible for the Physical Internet, only not with everyone having their own separate locker. Since the PI-containers should only be opened at the start and at the end point of the delivery, the PI-container should be delivered at the package locker point and serve as a locker. The receiver is the only one that can then open up the container.

6.4.4 Opening

The containers will only be opened at the start point and at its final destination. Therefore, a clear opening system is needed. The most important aspect is that the PI-container can only be opened by the person for which it was intended. This makes it possible to get the container from sender to receiver without opening the container. This is also important for the package lockers that the PI-containers are intended to be as well. In Landschützer et al. (2015) there is a locking system presented for MODULUSHCA boxes.
6.4.5 Implementation

Before the Physical Internet, and thus these containers, will be implemented, a lot of time will pass. The Physical internet will not exist from one day to another. Gradually, more and more routes will involve the PI. This will have to start somewhere. For example, the route between the port of Rotterdam and Singapore start with the implementation of the PI. For this to be possible, first the hubs must be built or existing hubs must be customised to make it functional for PI. This will cost a lot of money, which might not be profitable, since the amount of routes and connections it can be used for, is still very slim.

If the PI is implemented, all the containers have to be a standard size. It should be regulated that every hub that is being placed has the same tools to handle the same size of container in the same way as it happens in other ports and hubs.

Lets say a shipment comes from Singapore to Rotterdam. When it arrives in Rotterdam, the port must be able to identify each container and know where it has to be shipped to. The hub should contain all the necessary attributes to make sure the container can be received, split in the different separate container and it should be able to allocate these containers to the next mode of transport to make sure the shipment continues the journey to its final destination.

Now, the shipment is on its way to the hinterland of the port. The receiver of the shipment should be able to handle and open the package. This will at the implementation stage require a lot of changes within a company. All of the standards the company had, will need to apply to those of the physical internet. In the worst case, this means it has to get rid of the material it is currently using and invest money in new equipment suited for the Physical Internet. Therefore, it is the question whether companies want to be the first to take the step towards Physical Internet and if they want to make investment in a concept that is yet to be implemented.

6.4.6 Packaging

Since the goal is to leave as little space as possible unused, the packaging could be changed as well. However, packaging helps to attract the attention of the customer. This leads to uncertainty whether manufacturers would want to change their packaging to make it more suitable for the physical internet.
7 Conclusion

7.1 Conclusions

In this research, two methods were analysed. The first derived the possible PI-container sizes from the data available, while the other first chose the dimensions based on a possible combined container size and took fractions from this to determine what the sizes would need to be. The first method first looks whether items will fit and then chooses sizes, while the other first chooses sizes and then looks whether they will fit. The first leads to less space wasted on empty travel, while the latter makes the combining of smaller containers into one combined container easier. The main conclusion that is derived from this research, is that a higher amount of sizes leads to less space wasted. It is however not ideal to have a big amount of sizes, since this will cause trouble when combining a container.

7.2 Recommendations

A recommendation would be to take a standard container and divide every side by two on several iterations to determine the preferred dimensions for PI-containers. This way, extra empty travel is created, but it makes the combining of a container easier.

7.3 Limitations

There are several limitations to this research. The first one is the amount of data. The amount of data in this research is quite small. With a bigger set of data, the findings in this research could have been more general, whereas it is now based on a very slim set of data.

The second limitation is that the research does not take other constraints into consideration besides the size of the dimensions. Other important factors like weight might impact the design and the size of the containers as well.

The third limitation is that this research only focused on the external dimensions, instead of the useful space within the containers. Reason for this is that the internal dimensions are not known yet. As can be seen in the discussion, there are multiple factors that influence the internal size of a container. Example of this is the locking mechanism. When the space that these factors require is known, the useful space within the container can be estimated.

7.4 Future research

The most obvious thing for future research to discuss would be to determine the actual sizes for Physical Internet containers. Other constraints can be taken into consideration to come one step closer to the creation of real containers suitable for the Physical Internet.

The combining of the container has to be examined in future research. It is stated that the combining will be easier. However the degree to which it is
easier is not examined. When the combining is not that different for parts of 1/3 instead of 1/2, the 1/3 could also be taken into consideration. A hybrid with more fractions is possible as well.

Future research is also needed to explore the possibilities with this kind of containers. Since the Physical Internet is just a concept that is not executed right now, there are many areas to be explored. Besides the ability to use the PI-containers as package lockers, there might be many more instances where it is a suitable object.
8 References


