Counting the crowd

TU Delft library

R.J.M. Menken

Student ID: 4488032
Supervisor: Winnie Daamen

TU Delft

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by

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Thesis committee:	Dr. ir. W. Daamen,	TU Delft, supervisor
	Dr. ir. Y. Yuan,	TU Delft
	Ir. R. P. Koster,	TU Delft

Preface

This report is commissioned by the TU Delft library to research a solution for the people counting problem. This report serves as a recommendation for the TU Delft library with the best solutions for counting the in- and outflow and calculating the occupancy of the building. The in- and outflow and occupancy patterns are described as well in order to give the TU Delft library the information about the patterns of the students that use the library.

I would like to thank Winnie Daamen for supervising me during this project and all the advice and feedback she has given. I also would like to thank Yufei Yuan and Rolf Koster for the support and feedback they have given me during the project. The same counts for my fellow students Jarco Vianen and Luc Stappers for reviewing and giving feedback on my work.

R.J.M. Menken
Delft, June 17, 2019

Summary

The TU Delft library is a frequently visited place. For the library it is important to know the occupancy to see when the maximum capacity is reached. The employees have tried to measure the occupancy with the use of people counting sensors. However, these sensors are not accurate and deliver unreliable data and this needs to be improved. So the goal of this research is to provide the TU Delft library with an advice which consists of:

- A recommendation about how to use the data.
- A recommendation about the location of the sensors.
- A recommendation which sensors are needed.

A method to improve the information derived from the sensor measurements has been developed. This has been done by gathering the ground truth with manual counting sessions. The ground truth is used to calculate the number of measurement errors. The relation between the measurement error and the number of measurements done by the sensors have been determined for the inflow and the outflow. This resulted in a parabolic relation between the number of measurement errors and the number of measurements done by the sensors. With an increasing number of measurements done by the sensors the number of measurement errors first increased and started decreasing after a certain point.

The relation between the number of measurement errors and the number of measurements done by the sensors is exponential. That means that the number measurement errors increased exponentially with an increasing number of measurements done by the sensors.

The location to place the sensors have been reviewed as well. The current sensor setup can be improved in two ways. The sensors are not mounted in an optimal way. This can be improved by mounting the sensors closer to the doors and placing them horizontal, since the sensors are currently hanging in an angle which moves the coverage area further away from the door. Another option to improve the current setup is by closing the door towards the coffee corner, since this door causes disturbing people motions underneath the sensors.

Other locations to place the people counting sensors have been considered. This resulted into an recommendation to place the sensors outside above the entrance door. This spot provides the best setting to measure the in- and outflow, since this is the only people motion underneath the sensors.

If the recommended location to place the sensors is chosen by the TU Delft library new sensors are required, because the current sensors are not suitable to be placed outside. Different sensors have been compared to each other. The sensor that is recommended is the FILR Brickstream 3D. This sensor has an accuracy of 95%. It can give the real time occupancy, in- and outflow information and it is suitable to be placed outside. The V-Count 3D Alpha+ is another sensors that has been compared and is recommended if the sensor is placed inside. This sensors can give the real time occupancy, in- and outflow information as well. It has an accuracy of 98% according to the manufacturer, but it is not suitable to be placed outside. Another sensor that is recommended if the sensor is placed inside is the Irisys Gazelle. It can count real time and has an accuracy of 99% according to the manufacturer. However, it is not suitable to be placed outside.

The last part of this research is to determine and compare the in- and outflow patterns in the TU Delft library. These patterns have been determined for three different type of days, normal days, exam period days and holidays. The in- and outflow in the highest during the exam periods and the lowest during the holidays. The times of the in- and outflow peaks are depended on the average time that students have lunch and dinner. So is the inflow the highest after lunch time between 13:00 and 14:00. The outflow is the highest before lunch time between 12:00 and 13:00 and before dinner time between 17:00 and 18:00.

The occupancy patterns have been determined as well. It is not possible to calculate the exact occupancy because of the difference in in- and outflow measurement errors. The improving functions are not reliable enough to solve this problem. What can be said about the occupancy patterns is that the occupancy of the library is the highest during the afternoon.

Contents

1 Introduction

The TU Delft library is a frequently visited place on the campus. According to the sensors above the entrance doors, over 1.4 million people entered the library in 2018. It is open between 8:00 am and 0:00 am and during exam periods the TU Delft library is opened until 2:00 am.

The library employees have difficulties precisely counting the number of people going in and out of the library during different times of the day. These counts are made by several sensors placed in the building. However, the data delivered by those sensors is not accurate, because of an unknown measurement error. Based on the current measurements the outflow of people in the library is larger than the inflow.

These accurate counts are necessary for the library to have a clear view on the exact occupation. This is important to know because the capacity is limited during during the busy moment, for instance during the exam periods. It has been tried before by the library to find a proper solution in order to get the right data. However, the solution to this problem has not yet found. So a further research to his problem is necessary.

1.1. Current situation at the library

To find a solution to the inaccurate people counting sensors a research need to be done. Before this research can be started the current situation needs to be reviewed. This is done by a description of the layout of the entrance hall and the location of the sensors.

There is only one regular entrance with two doors to enter the library. Behind those doors is an entrance hall, marked blue in figure 1.1. From the entrance hall it is possible to go into three different rooms, namely the Coffee corner (marked in orange), a room with some vending machines (marked in green) and the main hall of the library. As can be seen in figure 1.1, the door for going into the coffee corner from the entrance hall is very close to the door for entering the building. Figure 1.2 shows the most common people motion in the entrance hall of the TU Delft library. All lines can be walked in both directions.

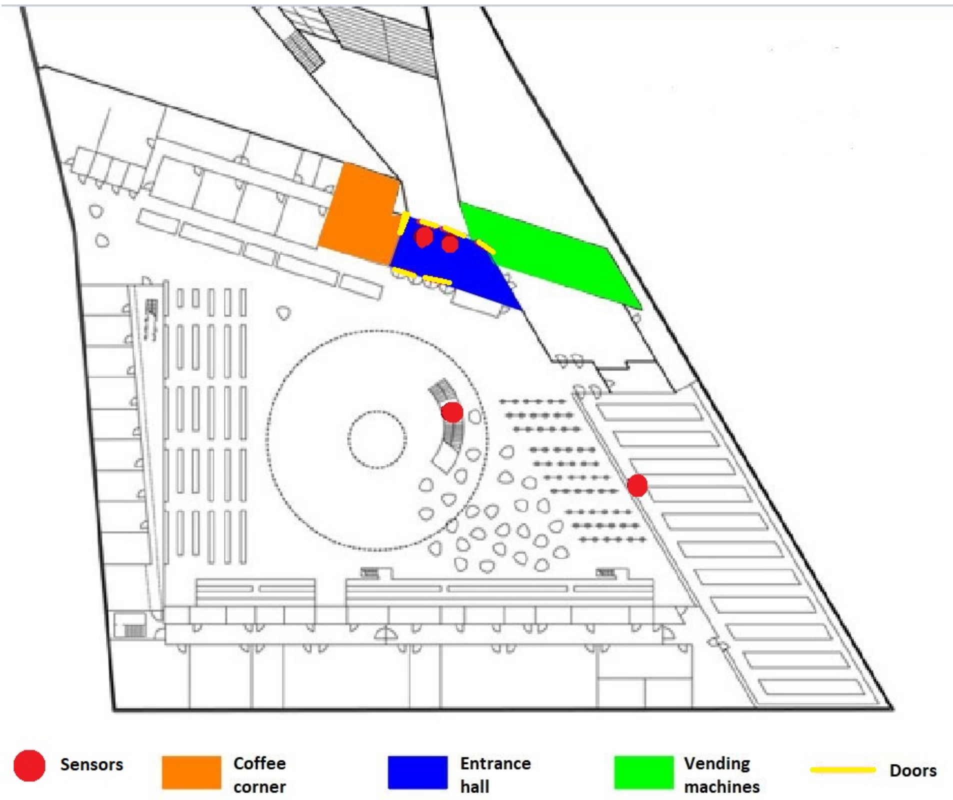


Figure 1.1: Map of the library with the Entrance hall, coffee corner and room with vending machines highlighted.

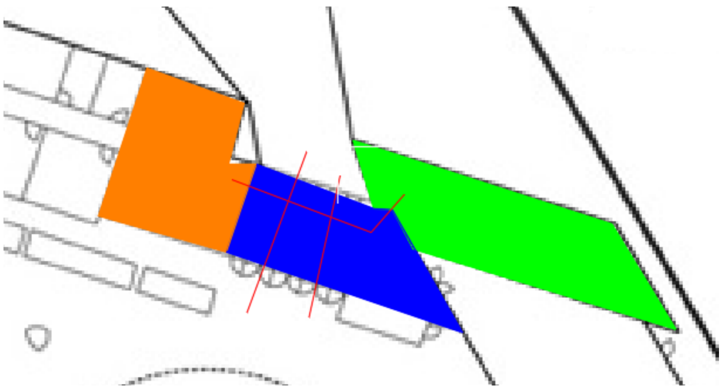


Figure 1.2: The common people motion in the entrance hall of the TU Delft library.

The TU Delft library has currently four people counting sensors installed. Two of them are installed in the entrance hall, one is installed above the stairs leading into the cone and the last is installed above the entrance of the silence and computer room. The counting of people entering and leaving the library building is done with two sensors above the entrance doors. The data delivered by those sensors are not reliable enough. There is a significant difference in the amount of inflow and the outflow of people. In 2018 the measured inflow was 1.476.526 people and the measured outflow was 1.543.925.[1] So there is a difference of -67.399 people. This means that either the inflow or outflow is not measured correctly, or both.

The TU Delft library wants to have more specific numbers about the occupation and in people flow patterns of the library at several moments. Because of the measurement errors made by the sensors is this not yet possible and this is why the TU Delft library commissioned for a research on the sensors. This research should lead to a better way to derive the in- and outflow information from the data that is more accurate than that is possible in the current situation. This can then be used to see patterns over the course of a day and to calculate the occupation of the library.

1.2. Goal

Now the problem description is clear, the goal for the research needs to be specified.

The goal of the client, the TU Delft library, is to answer questions about the in- and outflow patterns and the occupancy of the library during several moments of the day. To get this information, a good way to measure the real in- and outflow of people in the library needs to be determined. However, this is not yet possible with the current sensor setup and this needs to be improved. And it is important to analyse the in- and outflow patterns during different moments. So this leads towards two main research questions that need to be answered:

- What needs to be improved regarding the sensor data and placement to provide the TU Delft library with good information about the in- and outflow of people?
- What are the in- and outflow patterns at the entrance of the TU Delft library?

This means that the current sensors, the Count Cam MED[2], need to be evaluated. The locations where the sensors are placed need to be evaluated as well. Doing this should lead to an advice about the use of sensors to count the people going in and out of the library. This advice needs to consist of:

- A recommendation about how to use the data.
- A recommendation about the location of the sensors.
- A recommendation which sensors are needed.

1.3. Sub-Questions

In order to answer the main research question and get to the advice, some sub-questions need to be answered as well. The first sub-questions are about reviewing and improving the sensor setup. So those are necessary to answer the first main research question.

- How is the data measured by the current sensors compared to the real in- and outflow?
- What factors are responsible for the measurement error?
- What needs to be done to improve the information derived from the data gathered by current sensors so that it approaches the real values?
- What needs to be improved about the locations where the sensors are currently placed?
  - What information do the sensors give at the current locations?
  - Which locations are better to place the sensors in the TU Delft library?
- What are the advantages and disadvantages of different types of sensors?

The second main research question is to provide the TU Delft library with good information about the in- and outflow of people. Questions that need to be answered regarding this part of the research are:

- What is the pattern of people entering and leaving the library over a day?
- What is the difference in maxima of the in- and outflow graph, during different kind of days like holidays, exam periods and normal days?

2 Methodology

Now the goal of the research and with that the research questions are known, the methodology to answer the questions can be specified. It will consist of the following parts:

- 2.1 Review of the sensors: A literature study to get a better view on the currently used sensors
- 2.2 Gathering data: Data collection to quantify the measurement error and the data can be used for the next step
- 2.3 Improving the information derived from the data: in this step a data analysis will be done to determine a method to improve the measured data.
- 2.4 Location review: based on the observations done during the data gathering phase, the locations of the sensors will be reviewed.
- 2.5 Comparing to other sensors: A literature study in other types of sensors will be done.
- 2.6 Analysing the data: during this step a data analysis of the information about the in- and outflow of the library will be done.

2.1. Review the current sensors

The first sub question is about the difference of data measured by the sensor and the real values. Before determining this difference, it is important to find information about the current sensors. Important information is about the theoretical accuracy of the sensors, the way that they should be mounted and the way the people get counted by the sensors. The information about how the sensors should be mounted and the way how they count people is used to check if the sensors are mounted correctly in the current situation and this information is used in the location review as well.

2.2. Gathering data

In order to determine the measurement error, a value to compare the measured value to needs to be determined. This is the so-called ground truth and is obtained by manual counting. The manual counting is done in multiple sessions of an hour. The minimal time frame to obtain the data measured by the sensors is one hour, so that is the reason for counting sessions of an hour. During such a session the people going into the building and people leaving the building are counted. This is done for both sensors in the entrance hall at the same time, because it is not possible to see the data of both sensors separately. The data measured by the sensors ins stored in an online data base that is managed by Dancount, the company that produced the sensors[1]. To check if the plan is appropriate, a pilot is done. The minor flaws in the plan can be noted during this pilot and those are improved afterwards.

2.3. Improving the information derived from the data

When the ground truth of the in- and outflow of people is known, the data measured by the sensor is compared to this number. The difference can be calculated and expressed into a percentage. This percentage is calculated by the number of errors divided by the ground truth. After this is done, the possible factors responsible for the difference are given. Those are based on observations done during the counting sessions.

After determining the factors, more measurements under different circumstances are done. This can prove if and how much those factors matter. A possible factor is the number of people that pass the sensor at the same time, because the sensor might recognize two people as one. To prove if this is true manual count at busy and quiet moments need to be done.

The data that is gathered in the gathering data step has to be analysed to improve the information derived from the measured data by the sensors. It is necessary to formulate a function which uses the data measured by the sensors as input. The output will have to approach the real values as closely as possible. To do this the relation between the number of counts done by the sensors and the percentage and number of measurement errors is determined. Then with the use of Python the functions can be fitted and the best option is determined with the coefficient of determination (R^2). This fitted function is used to make the function that improves the information derived from the measured data by the sensors.

2.4. Locations

Another way to get more representative data that should be considered is the location of the sensors. First the current sensor setup is reviewed and possible improvements are determined. Then other suitable locations for the sensors need to be searched for. When this is done the advantages of these locations need to be specified. And the last step is to compare the advantages and disadvantages to give a recommendation.

2.5. Comparing to other sensors

This step in the research is to do a literature study that compares different sensors, which are based on different techniques[3]:

- Infra-red
- Cameras
- WIFI

The focus of this literature study is on the advantages and disadvantages of the different techniques. The first step is searching for information about the different sensors. Once this is done, a comparison between different sensors can be made. This is done by comparing the advantages and disadvantages to each other. Then the recommendation about which sensor to use is given.

2.6. Analysing the data

During this step the data measured by the sensors is used to determine the pattern of the in- and outflow of people in the library. The first thing that is analysed is the pattern of people entering and leaving over the course of a day. Important for the library to know about the pattern is to see when and how much the maxima and minima of the in- and outflow are. And if the patterns are similar during different types of days, like normal days, holidays and exam periods. The last thing is to calculate occupancy of the library and describe the occupancy pattern over the course of the day.

3 Sensor Review

To answer a part of the first main research question: What needs to be improved regarding the sensor data and placement to provide the TU Delft library with good information about the in- and outflow of people?, it is necessary to review the current sensors. What is important is a good view of the theoretical accuracy of the sensors in order to check if the current measurement error is due to the sensor or if other factors are responsible. The way that the sensors should be mounted is important to know, because this could be a reason for the measurement error as well. And the way that the sensor measures people going in and out of the building is important to know, in order to determine how the sensors should be placed.

The sensors that are currently used in the TU Delft library are the CountCam MED, fabricated by the Danish company Dancount[4]. It is a overhead people counter, that means that it count people walking underneath it. The sensor uses a camera to identify people passing it. It can count multiple people passing the sensor in the same or opposite direction. The sensor should be mounted on the ceiling above the point where the measurement is needed. In normal conditions, the sensor has a counting accuracy of 95%.

The optimal mounting height of the sensor in standard configuration is between 250 and 750 cm. The coverage area of the camera increases when the sensor is mounted higher. Figure 3.1 shows the coverage width in relation with the mounting height. It shows that the coverage width is between 225 cm and 1050 cm.[2] The coverage width is the length of the virtual line which people need to cross in order to get counted.

Install height Type cms	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
CC-MED	**225**	**300**	**375**	**475**	**550**	**625**	**725**	**800**	**875**	**975**	**1050**					

Figure 3.1: A table with the mounting height and the coverage width of the CC MED[2]

When the sensor is mounted above a sliding door it should be mounted near the door to get optimal counting results. And if the sensor is mounted after swinging doors the sensor should be installed further away from the door, so that the door movement will not be counted. However, the path towards the sensor should be limited so that it insures that the people walk underneath it. Figure 3.2 is retrieved from the installation manual of the CC-MED and shows the correct mounting instructions.

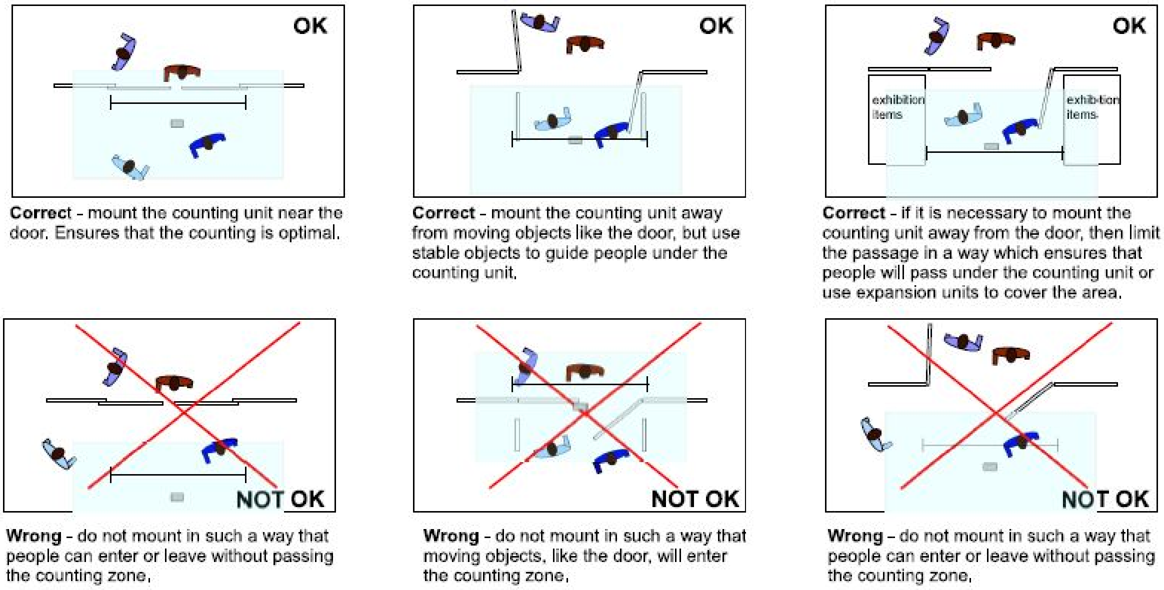


Figure 3.2: The mounting instructions for the CC-MED.[2]

The coverage area is the area underneath the sensor, in which it can detect people movement. A virtual line is drawn in that area. If a person crosses that line it will be counted by the sensor as a movement in or out of the building. Figure 3.3 shows the coverage area with the virtual line in the middle. This makes in clear why people should be guided to walk underneath the sensor in order to get counted by it. If the sensors are placed too far from the door, it is possible to walk around the coverage area and still enter or leave the building.

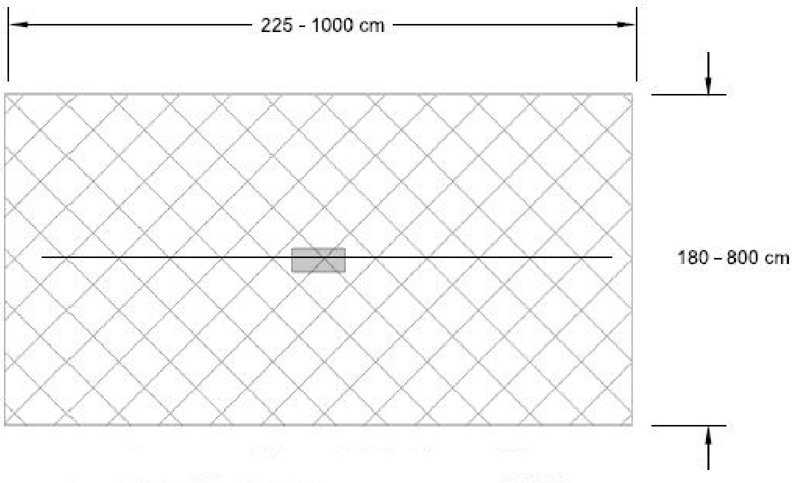


Figure 3.3: The coverage area of the CC MED[2]

The sensors are made for indoor use. So the sensors are not suitable to be placed outside.

So this concludes this chapter about the review of the currently used sensors. The information in this chapter can be used for determining the factors responsible for measurement errors and for the location review.

4
Data analysis

This chapter contains the gathering data and improving the information derived from the data steps of the methodology described in chapter 2. First the data that is gathered during the manual counting sessions is compared to the ground truth. Then the responsible factor for the measurement error are clarified. And finally the function to improve the information derived from the measured data by the sensors is determined.

4.1. Gathering data

So the first step is to gather the ground truth of the in- and outflow of people. That is done by manual counting the people going in and out of the building. The ground truth is needed to calculate the measurement error of the sensors, which then can be used for determining the best method to improve the information derived from the measured data by the sensors.

The counts that are be done during the manual counting sessions are recorded by the use of a data-logging software that stores the keyboard buttons pressed including a time stamp in a text file, the f button for the inflow and the j for the outflow. By the use of a python script that counts the f and j letters in the text file, the in- and outflow numbers can be counted.

Figure 4.1 shows the map of the library. The sensors that are analysed are above the two entrance doors, coloured in red. The blue circle is the location to sit while counting. This spot provides a good overview over the area and it does not block any of the students who enter the library. Another positive is that it has access to power so that the laptop can be charged when needed. As has been described in chapter 2.2, the data of the sensors is only available in sections of an hour. So the minimal counting time will be one hour.

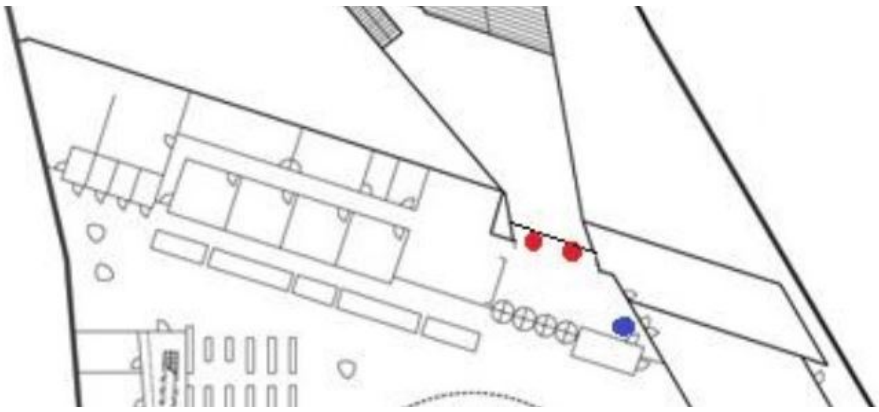


Figure 4.1: Map of the entrance of the library with the two sensors above the entrance doors in red and the place to sit while counting in blue.

4.1.1. Pilot

The pilot has taken place on Friday May 10, 2019 between 12:00 and 13:00. The results for the counting session were: 369 walking people into the library and 327 walking people out of the library. The measured inflow is 396 people and the measured outflow is 364 people. The difference between the measured values and the counted values is 27 for the inflow and it is 37 for the outflow as can be seen in table 4.1.

During the first counting session tally marks were used to count the people walking in and out of the library. However, this was not the best idea to use for counting the people. By writing down the tally marks the focus is switched away from the door. When it is busy it is easy to miss some of people walking in or out of the library. So it is better to find a way of counting people without having to switch focus from the door, like a clicker or software on a laptop. So from this point the data-logger software is used to record the number of people walking in and out of the entrance door of the TU Delft library.

4.1.2. Counting results

After the pilot, more counting sessions have been done. The results of the number of people walking in and out of the TU Delft library are noted in table 4.1.

Table 4.1: Results of the Manual counting sessions.

Date & Time	Counted in	Counted out
10-5-2019, 12:00 - 13:00	369	327
13-5-2019, 11:00 - 12:00	232	176
14-5-2019, 11:00 - 12:00	264	206
15-5-2019, 11:00 - 12:00	322	246
15-5-2019, 12:00 - 13:00	409	497
16-5-2019, 17:00 - 18:00	297	417
17-5-2019, 15:00 - 16:00	225	250
20-5-2019, 15:00 - 16:00	403	345
21-5-2019, 11:00 - 12:00	303	284
21-5-2019, 12:00 - 13:00	369	473
23-5-2019, 17:00 - 18:00	262	398
28-5-2019, 17:00 - 18:00	232	412
5-6-2019, 13:00 - 14:00	486	372
6-6-2019, 13:00 - 14:00	504	406

4.1.3. Comparing the ground truth to the sensor data

To keep track of the results of the different counting sessions and the data measured by the sensors in the same periods, a table is made. Table 4.2 shows the data measured by the sensors and the results of the manual counting session. It also shows the difference between the measured data by the sensors and the ground truth obtained during manual counting sessions. The last two columns of the table show the percentage of measurement errors in comparison to the ground truth. So this means that the measurement error values are divided by the counted values and multiplied by 100%.

Table 4.2: Results of the Manual counting sessions compared with the measured values.

Date & Time	Measured in	Measured out	Counted in	Counted out	Error in	Error out	Percentage error in	Percentage error out
10-5-2019, 12:00 - 13:00	396	364	369	327	+27	+37	7,3%	11,3%
13-5-2019, 11:00 - 12:00	258	204	232	176	+26	+28	11,2%	15,9%
14-5-2019, 11:00 - 12:00	274	229	264	206	+10	+23	3,8%	11,2%
15-5-2019, 11:00 - 12:00	346	264	322	246	+24	+18	7,5%	7,3%
15-5-2019, 12:00 - 13:00	423	494	409	497	+14	-3	3,4%	-0,6%
16-5-2019, 17:00 - 18:00	341	607	297	417	+44	+190	14,8%	45,6%
17-5-2019, 15:00 - 16:00	260	285	225	250	+35	+35	15,6%	14,0%
20-5-2019, 15:00 - 16:00	465	426	403	345	+62	+81	15,4%	23,5%
21-5-2019, 11:00 - 12:00	339	321	303	284	+36	+37	11,9%	13,0%
21-5-2019, 12:00 - 13:00	390	497	369	473	+21	+24	5,7%	5,1%
23-5-2019, 17:00 - 18:00	310	589	262	398	+48	+191	18,3%	48,0%
28-5-2019, 17:00 - 18:00	250	545	232	412	+18	+133	7,8%	32,3%
5-6-2019, 13:00 - 14:00	490	409	486	372	+4	+37	0,8%	9,9%
6-6-2019, 13:00 - 14:00	488	429	504	406	-16	+23	-3,2%	5,7%

A conclusion that can be drawn from table 4.2 is that the sensors usually measure more people walking in and out of the library than that is actually the case. Only during two hours where a counting session took place was the error negative, one for the outflow during session 15-5-2019, 12:00 - 13:00 and one for the inflow during session 6-6-2019, 13:00 - 14:00. This is not what is expected from people counting sensors. Usually these kind of sensors miscount some people instead of counting extra people. Reasons for this will be discussed later on in this chapter.

Three counting sessions have been done between 17:00 and 18:00. During these counting session the error for the outflow is larger than during the other counting sessions. A reason that is responsible for this fact is the behaviour of people that differs between different times of a day. This is explained in more detail at the end of this chapter.

4.1.4. Responsible factors measurement error

An important factor that might be responsible for the measurement error is the door towards the coffee corner, immediately next to the entrance door, see figure 1.1 in Chapter 1, Introduction, for an overview of the entrance hall. The door is frequently used by students and even some queues appear when multiple people want to go through the door at the same time. Some of those people pass the sensor and it is unclear whether they are counted or not. This explains the reason why these sensors count more people walking in and out of the building, than that is actually the case. Since some of the people walking through this door are counted although they did not enter or leave the building.

In order to prove if this door is responsible for the measurement error, some counts with the door closed have to be done. The results of those counting sessions in comparison with the data measured by the sensors are shown in table 4.3.

Table 4.3: Results of the Manual counting sessions compared with the measured values, when the door towards the coffee corner was closed.

Date & Time	Measured in	Measured out	Counted in	Counted out	Error in	Error out	Percentage error in	Percentage error out
22-5-2019, 11:00 - 12:00	357	259	351	240	+6	+19	1,7%	7,3%
22-5-2019, 12:00 - 13:00	410	614	441	585	-31	+29	-7,6%	4,7%

The mean measurement error for the inflow is -2.7% and the mean measurement error for the outflow is 6.4%. These values can be compared to the average measurement error that has been determined in the normal situation. For the inflow is it 7.3% and for the outflow is the average measurement error 9.0%. These averages are calculated for only the counting sessions between 11:00 - 12:00 and 12:00 - 13:00. What can be concluded is that the measurement error is slightly lower when the door was closed. This indicates that the flow of people through the door towards the coffee corner disturbs the sensor measurements. Only two measurements have been done with the door closed, this is not enough to prove if the door is fully responsible. However, it gives an indication so it will be assumed that the different motions underneath the sensor caused by the door are responsible for a part of the measurement error.

Another factor responsible for the measurement error of the sensors is the way that the sensors are mounted. The first thing that stands out is that the sensors are placed too far away from the doors. The doors leading into the hall of the library are sliding doors. As has been discussed in chapter 3, the sensors should be mounted close to a sliding door and if this is not possible the passage way underneath the sensors should be limited so that all people walk under neath the sensors. This has not been done in the current situation. The second thing that stands out is that the sensors are placed flat on the ceiling. However the ceiling is sloped, so the sensors are placed in an angle. This means that the coverage area of the sensors is further away from the door than that it would be if the sensors are placed flat. This factor also leads to the fact that more people motions are possible underneath the sensors than only the in- and outflow of people in the library building.

4.2. Improving the data interpretation

The data that is gathered is plotted, so that it is easier to find a certain pattern in the values. Different colours have been used for the dots to show the time slots in which the values were gathered.

The first plot that is made is figure 4.2. It shows the pattern between the ground truth and the values measured by the sensor. Ideally those values are on the line y = x, so that the measurement error is 0. However, almost all values lay above this line. That means that the values measured by the sensors are higher than the ground truth. So More people are measured by the sensors than that actually enter or leave the library building. The conclusion that can be drawn from this figure, is that the sensors generally count more people than that is actually is the case. Another thing that can be concluded from this figure is that the measurement error is larger for the outflow than the inflow, especially for the outflow values between 17:00 and 18:00.

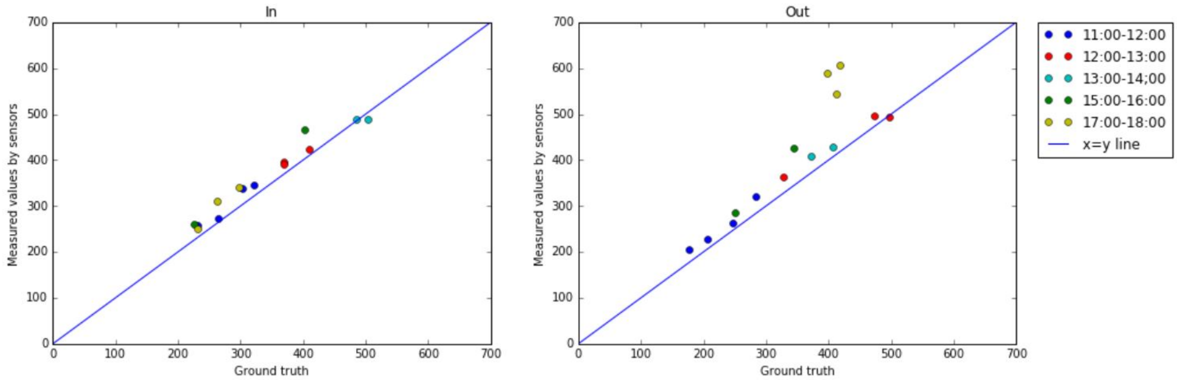


Figure 4.2: The ground truth on the x-axis and the measured values by the sensors on the y-axis. Left: inflow. Right: outflow.

The next plot that is made is figure 4.3, it shows the measured values by the sensors on the x-axis and the percentage of measurement error on the y-axis. This percentage is calculated by dividing the measurement error by the amount of measurements made by the sensors. And figure 4.4 shows the measured values by the sensors on the x-axis and the number of measurement errors on the y-axis. What can be seen in the figures is that for the inflow the measurement error decreases when more measurements are done by the sensors. For the outflow happens the opposite, namely the measurement error increases when the number of measurements done by the sensors increase. Possible reasons for this relation will be given after the exact relation has been determined.

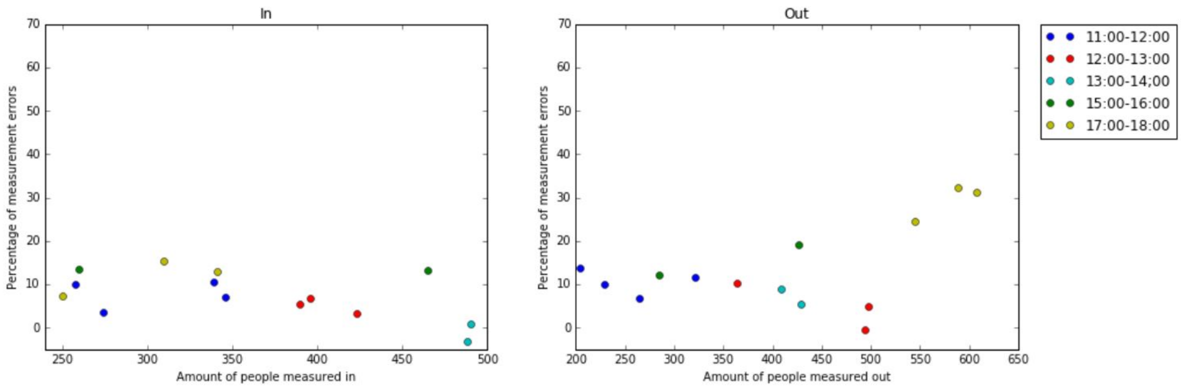


Figure 4.3: The measured values by the sensors - Percentage of measurement errors. For the inflow on the left and outflow on the right.

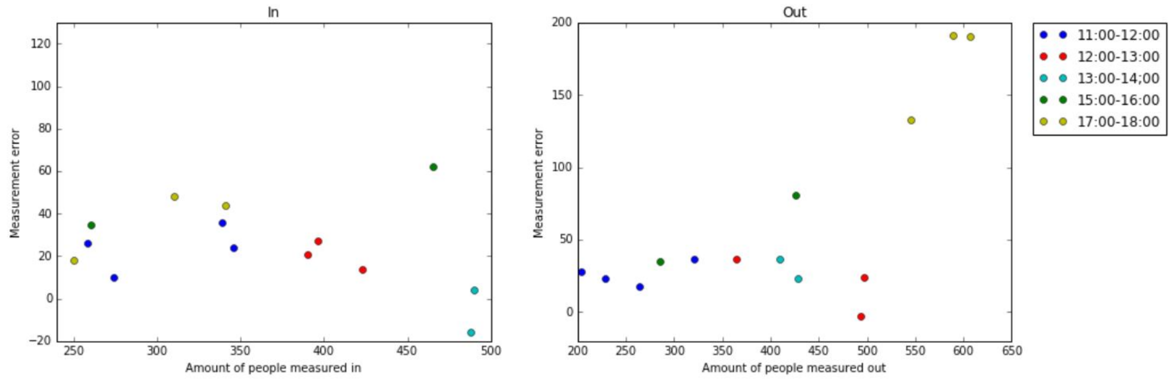


Figure 4.4: The measured values by the sensors - Number of errors made. For the inflow on the left and outflow on the right.

Figure 4.3 and 4.4 can be used to determine a relation between the measured values by the sensors and the measurement error. Which then can be used to improve the information derived from the sensor measurements.

In order to do this different relations have been fitted in the graphs. This has been done with the use of the linregress and curve_fit package in Python. Then the different fits can be compared to each other. This comparison has been done by calculating the Root mean square error and the coefficient of determination. The Root mean square error can be used to compare the functions fitted in the same graph and the coefficient of determination can be used to give an overall comparison between the fitted plots.

First the fitted functions for figure 4.3 have been made. The functions for the inflow are shown in table 4.4 and the functions for the outflow are shown in table 4.5. The plots of these fitted functions are shown in appendix A.

Table 4.4: Fitted functions for the inflow of figure 4.3 with the root mean square error and coefficient of determination

Type of function	Function	Root mean squared error	R^2
Linear	-0.0324 * x + 19.3	4.46	0.261
Parabola	-0.000276 * x^2 + 0.171 * x - 16.5	4.18	0.352
Exponential	- 1.01 ^x + 14.5	4.32	0.308
Logarithmic	71.1 - 10.8 * log(x)	4.56	0.230

Table 4.5: Fitted functions for the outflow of figure 4.3 with the root mean square error and coefficient of determination

Type of function	Function	Root mean squared error	R^2
Linear	0.0372 * x - 1.45	8.22	0.249
Parabola	0.000376 * x^2 + -0.268 * x + 54.2	6.16	0.578
Exponential	1.01 ^x + 3.37	7.18	0.426
Exponential	2.65e-32 * x ^11.9 + 9.56	5.63	0.647

The conclusions that can be drawn from table 4.4 and 4.5 it that the best function to describe the inflow relation between the number of measurements done by the sensors and the percentage of measurement errors is a Parabola:

$$P = -0.000276X^2 + 0.171X - 16.5 \tag{4.1}$$

And the functions to describe outflow relation between the number of measurement error by the sensors and the percentage of measurement errors is an exponential function:

$$P = 2.65e - 32X^{11.9} + 9.56 \tag{4.2}$$

With:
P: percentage of measurement error

X: Number of measurements done by the sensors

The reason that these are determined as the best functions is because the root mean square error is the lowest and the coefficient of determination is the closest to one. The inflow relation between the number of measurements done by the sensors and the percentage of measurement error is parabolic. This means that the percentage of measurement errors first increases and after a certain point decreases. The main reason that the measurement error decreases is because of the low measurement error that occurred in the counting sessions between 13:00 and 14:00. The inflow was the highest in that hour, so that makes the relation between the percentage measurement error decrease with a higher number of measurements done by the sensors. The outflow relation is exponential, so that means that means that the Percentage of measurement errors stay about the same and after a certain point start increasing rapidly. The main reason for the exponential relation is that the percentage measurement error stays about equal for the most measurements that are done. However the percentage of measurement errors is significantly higher in the counting sessions between 17:00 and 18:00. And the outflow was the highest in this hour, so that makes that the relation is exponential. These functions have been visualized in figure 4.5.

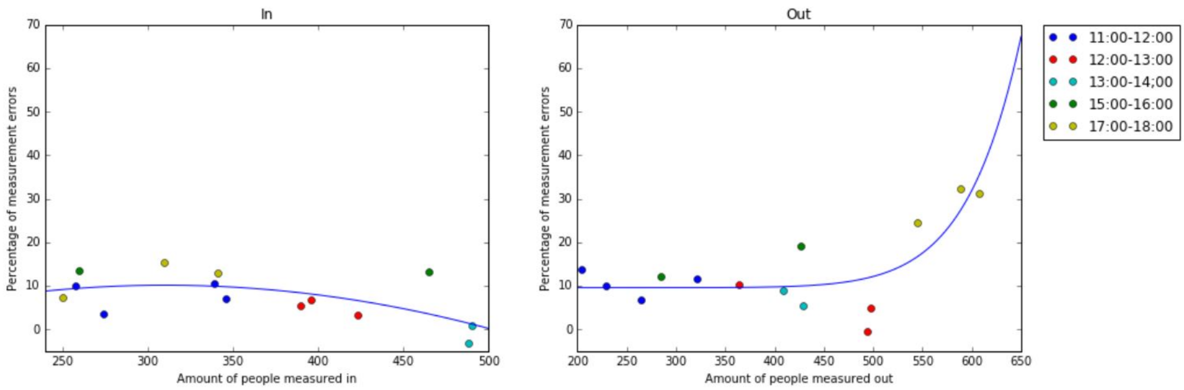


Figure 4.5: The fitted line for the relation between the number of measurements done by the sensors and the percentage of measurement errors. Left: inflow. Right: outflow

The same has been done for the relation between the number of measurements done by the sensors and the number of measurement errors. Table 4.6 and 4.7 show the functions that have been fitted and the tables show the root mean square error and the coefficient of determination. The plots of these fitted functions are shown in appendix A.

Table 4.6: Fitted functions for the inflow of figure 4.4 with the root mean square error and coefficient of determination

Type of function	Function	Root mean squared error	R^2
Linear	-0.0597 * x + 46.7	18.3	0.0666
Parabola	-0.00133 * x^2 + 0.923 * x – 125	16.7	0.226
Exponential	-0.970 ^x + 25.2	18.9	2.59e-07
Logarithmic	131 + -18.1 * log(x)	18.5	0.0479

Table 4.7: Fitted functions for the outflow of figure 4.4 with the root mean square error and coefficient of determination

Type of function	Function	Root mean squared error	R^2
Linear	0.336 * x - 74.8	44.2	0.482
Parabola	0.00214 * x^2 + -1.40 * x + 242	31.5	0.736
Exponential	1.01 ^x + 6.24	30.4	0.755
Exponential	4.82e-25 * x ^9.55 + 28.3	26.0	0.820

What can be concluded based on table 4.6 and 4.7 is that the best function to describe the inflow relation between the number of measurements done by the sensors and the number of measurement errors is a parabola:

$$N = -0.00133X^2 + 0.932X - 125 \tag{4.3}$$

And the best function to describe the outflow relation between the number of measurements done by the sensors and the number of measurement errors is an exponential function:

$$N = 4.82 * 10^{-25} X^{9.55} + 28.3 \tag{4.4}$$

With:
N: Number of errors
X: Number of measurements done by the sensor

The reason that these are the best functions is because the root mean square error is the lowest and the coefficient of determination is the closest to one. The best fitting inflow relation between the Number of people measured by the sensors and the number of measurement errors is parabolic. So again the number of measurement errors seem to increase with an increasing number of measurements done by the sensors, but after a certain amount of measurements done the number of errors decrease. As has been described before this decrease is because of the fewer number of measurement error in the counting sessions between 13:00 and 14:00 when the inflow was the highest The outflow relation between the Number of people measured by the sensors and the number of measurement errors is exponential. The number of measurement errors stay equal when the number of measurements increases, but after a certain amount of measurements done, the number of errors increase rapidly. This is mainly because of the counting sessions between 17:00 and 18:00 when the number of measurement errors was the highest. The fitted relations between the number of measurements done by the sensors and the number of measurement error for the in- and outflow have been plotted in figure 4.6.

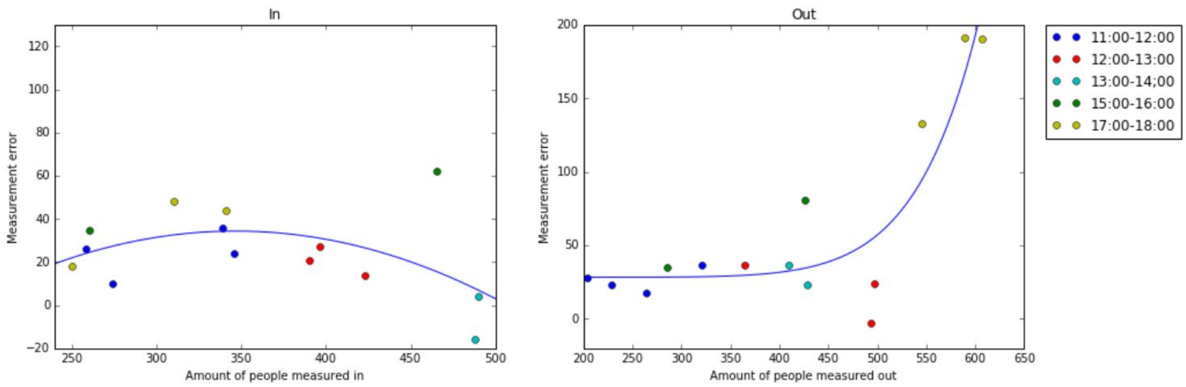


Figure 4.6: The fitted line for the relation between the number of measurements done by the sensors and the number of measurement errors. Left: inflow. Right: outflow

The fitted functions can be used to improve the information derived from the data delivered by the sensors. Two functions have been fitted for the in- and outflow. The first is to describe the relation between number of measurements done by the sensors and percentage of measurement errors. The parabolic inflow relation has an R^2 of 0.353 and the exponential outflow relation has an R^2 of 0.647. The second function describes the relation between the number of measurements done by the sensors and number of measurement errors. The parabolic inflow relation has an R^2 of 0.226 and the exponential outflow relation has an R^2 of 0.820.

By using the R^2 to compare the functions for the inflow relations, it becomes clear that the fitted function for the relation between the number of measurements done by the sensors and the percentage of measurement error is the best function to use to improve the information derived from the data delivered by the sensors. The formula to calculate the new inflow becomes:

$$I = X - (-0.000276X^2 + 0.171X - 16.5)/100 * X \tag{4.5}$$

With:
I: Number of people walking into the library building

X: Number of inflow measurements done by the sensors

By doing the same for the outflow relation, it becomes clear that the fitted function for the relation between the number of measurements done by the sensors and the number of measurement errors is the best function to use to improve the information derived from the data delivered by the sensors. The formula to calculate the new outflow becomes:

$$O = X - (4.82 * 10^{-25} * X^{9.55} + 28.3) \tag{4.6}$$

With:
O: Number of people walking out of the library building.
X: Number of outflow measurements done by the sensors

What must be noted about these functions is that there will not be a high reliability for these functions. The reason for this is the number of measurements that are done in the research is too low. This will be further elaborated in the discussion in chapter 8.

Figure 4.2 is used to show the relation between the measured values and the ground truth. This figure has been recreated to show the difference that the improving functions have made. This can be seen in figure 4.7.

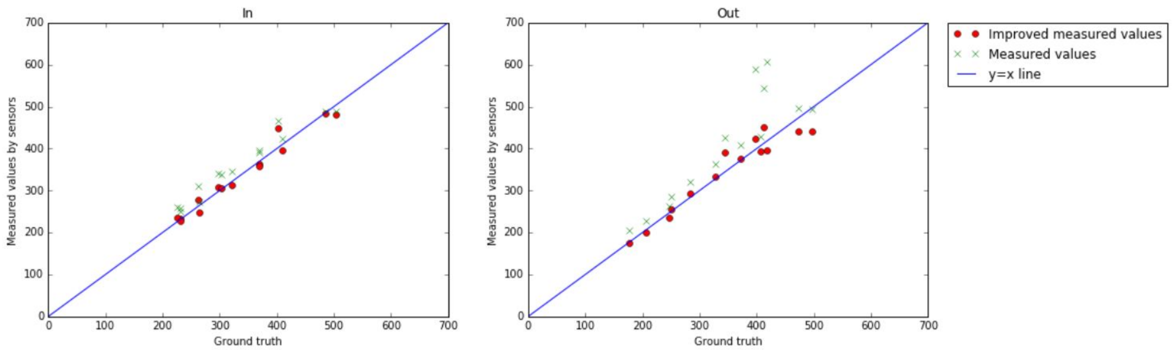


Figure 4.7: The relation between the ground truth and the (improved) measured values.

What can be seen is that the improved point are closer to the y = x line. To show this the root mean square error between the ground truth and the measured values has been compared with the root mean square error between the ground truth and the improved values. Table 4.8 shows the values for the root mean square error(R.M.S.E). It is clear the the R.S.M.E. is significantly reduces for the improved values.

Table 4.8: The root mean square error between the ground truth and the (improved) measured values

	R.M.S.E unimproved	R.M.S.E. improved
In	31.4	16.6
Out	86.6	26.0

The relation that has been investigated is between the number of measurements done by the sensor and the measurement error. An assumption for another relation for the measurement error is the relation between the time of the day and the number of measurement errors that occur. This can be explained by the fact that the values for each hour in figure 4.3 and 4.4 are quite clustered. So are the measurement error for each hour relatively similar. This give an assumption that there is a relation between the hour of the day and the measurement error. However not enough measurements have been done to prove if there is a relation. See the discussion in chapter 8 for more explanation.

The fact that the measurement errors are different during the different hours can be explained by the different behaviour patterns of people over the course of a day. So is the door towards the coffee corner and the toilet hall not equally used over the day. As has been stated before the use of this door disturbs the measurements that are done by the sensors. So when the door is used more, the measurements get more disturbed. The exact behaviour patterns of the people have not been researched, so the exact cause for the difference in results between the different time frames is not determined. See the discussion in 8 for a further elaboration on this topic.

5
Location Review

In this chapter different locations to place the sensors are reviewed. The current location is reviewed first. Then new possible locations are considered. And to conclude this chapter, a recommendation about the best possible location is given.

5.1. Current location

The TU Delft library has four people counting sensors installed in the current situation. Figure 5.1 shows the four locations, one on the right in the silence and computer room, one above the stairs leading into the cone and two above the entrance doors. As has been stated before, the main focus of this research is on measuring the in- and outflow. So only the two sensors in the entrance hall are considered. This means that the other two sensors are neglected.

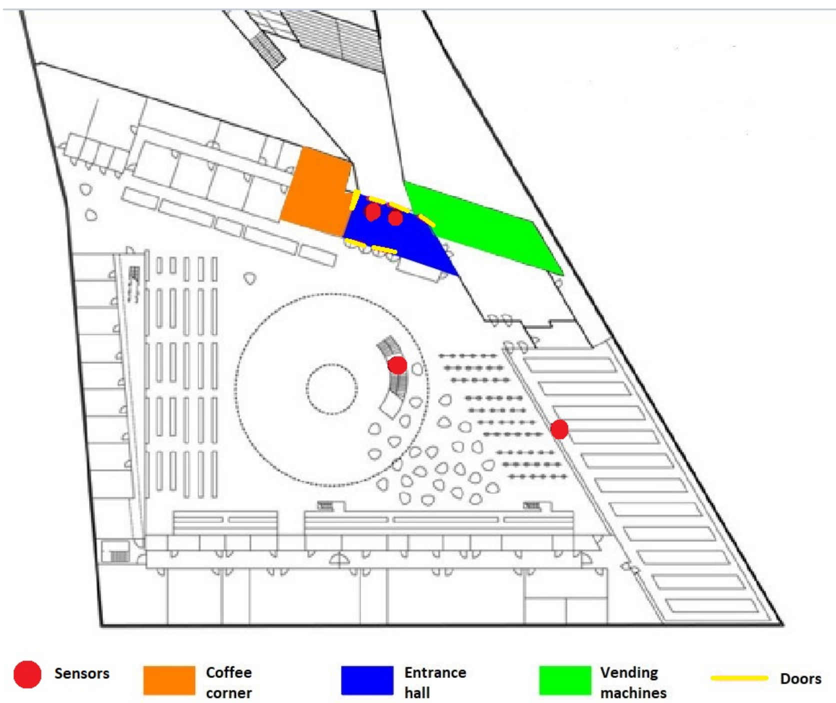


Figure 5.1: Map of the library with the Entrance hall, coffee corner and room with vending machines highlighted.

The goal of placing the sensors in this location is to measure the in- and outflow of people in the library. However, this is not the only people motion in the entrance hall. And some of these motions are measured as well and added to the in- or outflow numbers. Two factors of this sensor placement might enhance this problem. The first is that the sensors are not placed closely enough to the door. This makes it easier for the people who do not leave or enter the building to cross the sensors. The second factor is that the sensors are placed flat on the ceiling. However, the ceiling has a slope, so that means that the sensors are hanging in an angle. This moves the measurement point further away from the doors and increases the likelihood for the people who do not leave or enter the building to cross the sensors' coverage area and get counted.

It is possible to slightly improve the current sensor setup. The first step to do this is by moving the sensors closer towards the door. As has been described in chapter 3, this is the best way to install sensors next to a sliding door. The second step is mounting the sensors without and angle to the ceiling, so that the coverage area is closer towards the door. The next step is to limit the passage way underneath the sensor to make it only possible for people entering or leaving the building to walk through the coverage area of the sensors. The best way to do this is by locking the door towards the coffee corner. People who want to enter the coffee corner will have to go through the doors in the main hall of the library. This option will decrease the different people motions underneath the sensor, since the biggest disturbance, the people motion towards and from the coffee corner, will be gone. However, this option will complicate the movement towards the coffee corner as well and so it disturbs the students in the library and the coffee corner itself. Another option that has been considered is placing objects which guides people to walk underneath the sensors. However, there is not much space between the entrance door and the door towards the coffee corner. Therefor it will not be possible to open the door towards the coffee corner, so this is not a viable alternative.

So the conclusion is that it is possible to improve the current sensors setup. But reducing the biggest disturbance, closing the door towards the coffee corner, will be a big disturbance for the students and the coffee corner itself.

5.2. New location

The TU Delft library has two other locations that are suitable for measuring the number of people going in and out of the building. The first location that is considered needs four sensors and all sensors are placed inside. The second location that is considered needs two sensors which are placed outside.

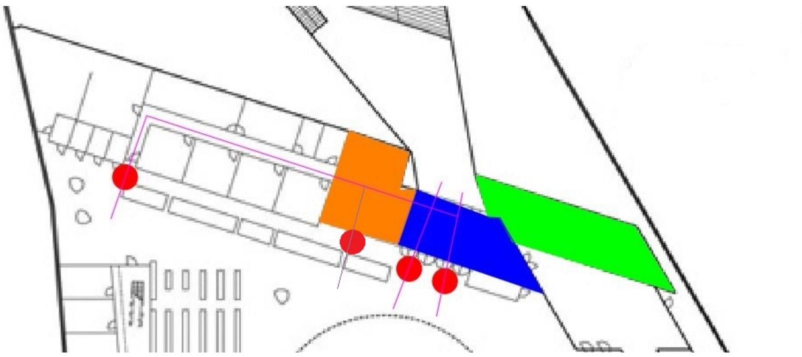


Figure 5.2: Map of the library with the new inside locations for the people counting sensors to measure the in- and outflow. With the possible waking routes

The first new locations for the people counting sensors are shown in figure 5.2. This setup needs four sensors to measure the in- and outflow of people in the library, because it is possible to enter the main hall of the library with four doors. Namely, the two doors at the end of the entrance hall and the door at the end of the hallway of the toilets and the door between the main hall of the library and the coffee corner. In this new setup the current sensors can be used since the sensors will be placed inside of the building. However, that means the in- and outflow towards the silence room and the cone cannot be measured anymore.

This setup can be used for determining the occupancy of the main hall of library for each hour. However, a downside for using this setup is that not the real in- and outflow of the library are measured, but the in- and outflow of the main hall of the library. The total occupation of the main hall of the library can be calculated, which is important to know to determine how much capacity is left at certain hours. However, the real occupation of the whole building cannot be determined with this sensor setup.

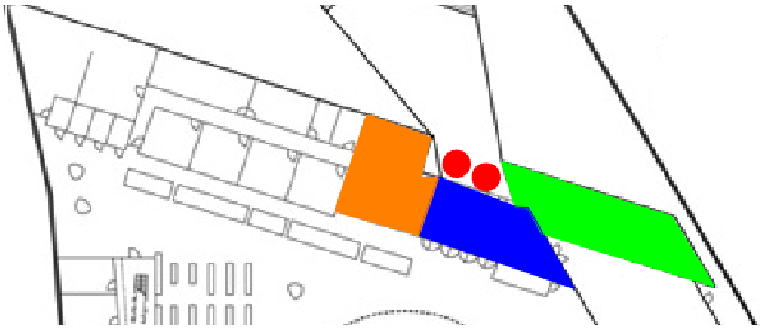


Figure 5.3: Map of the library with the new outside locations for the people counting sensors to measure the in- and outflow.

Figure 5.3 shows the second option for a suitable location to place the people counting sensors. This location requires two sensors and those are placed outside above the entrance door. This location is very suitable for measuring the actual in- and outflow of the library, since all people who enter or leave the library walk underneath the sensor and will be counted. A positive of this location is that no other people motion is common underneath the sensors, which could have disturbed the measurements. A negative of this location to place the sensors is that the current sensors cannot be used, because those are not suitable to place outside. So new sensors are required if this location is chosen as the best option.

5.3. Recommendation

In order to recommend the best possible location to place the people counting sensors, the advantages and disadvantages need to be compared. This is done by the following criteria:

- **Criterion A**: Is different people motion common underneath the sensors?
- **Criterion B**: Does this sensor setup measure the actual in- and outflow of the building?
- **Criterion C**: Can the current sensors be used for this setup to save costs?
- **Criterion D**: Are people disturbed by this setup?

These criteria are compared to each other in table 5.1. Four locations will be compared in the table. The old location is the current setup as it is used now. The old location with improvements is the current setup with the improvements that are described in section 5.1. New location 1 is the new location with the four sensors placed inside as can be seen in figure 5.2. New location 2 is the new location with the two sensors place outside as can be seen in figure 5.3.

Table 5.1: Comparison of the different sensor locations.

Criterion	Old location	Old location with improvements	New location 1	New location 2
A	Yes	No	No	No
B	Yes	Yes	No	Yes
C	Yes	Yes	Yes	No
D	No	Yes	No	No

What can be concluded from the table is that the old location is reduced in accuracy, since different people motion is common underneath the sensor. And these motions can be counted as well. The old location with improvements has as downside that the students are disturbed. Since it is impossible to reach the coffee corner from the entrance hall. New location 1 has as downside that not the real in- and outflow of the building are measured, but only the in- and outflow of the main hall of the library. New location 2 has as downside that the costs will increase, since new sensors have to be purchased.

Based on these criteria the best option to measure the in- and outflow of the TU Delft library building is to place the sensors outside above the entrance door. So this location will be recommended. However, if the TU

Delft library wants to save costs and keep on using the current sensors, the old location with improvements is recommended. Although this brings as downside that the coffee corner and the hall towards the toilets will be harder to reach for the students.

6 Comparison of sensors

This chapter contains a literature study to compare four different people counting sensors. First a literature study has been done to compare the most commonly used techniques for people counting sensors, which are infra-red, camera and WIFI[3]. This can be found in appendix B. Then the sensors that will be compared are discussed and the advantages and disadvantages are compared. From this comparison a recommendation about what sensor needs to be used is given.

Based on this literature study the most suitable sensors to use for people counting in the TU Delft library are the overhead thermal and video-based sensors. Now the different sensors that are based on the techniques discussed can be compared. The sensors that are compared to each other are the FILR Brickstream 3D Gen 2, V-Count 3D Alpha+, Irisys Gazelle 2 and FootfallCam 3D Plus.

6.0.1. FILR Brickstream 3D Gen 2

This sensor can be delivered by HSBIB, the company that also deliver the current sensors. This sensor is based on a stereo camera technique. This means that two cameras work together so that it is possible to see depths. So adults and children can be distinguished by the sensor. However, this is not really necessary for the TU Delft library, since barely any children visit it. Another positive of the stereo technique is that the sensors are less sensitive for a change in light level.

The FILR Brickstream 3D Gen 2 has an accuracy of 95%. It is suitable for large people flows, with a maximum of 5,000 people per hour. So even with a flow of 5000 people per hour the sensors keep the accuracy of 95%.

The FILR Brickstream 3D Gen 2 should be placed on a height between 2.4 and 10 metres. For a height higher than 6 metres a special lens can be delivered. If the sensors need to cover a wide area, multiple sensors can be placed in line and work together without double counting people. The sensor can be placed both inside and outside.[5]

With this sensor it is possible to get a real time report of the occupancy of the building. It is even possible to display the real time occupancy of the website of the TU Delft library, so that students know how crowded it is.

6.0.2. V-Count 3D Alpha+

The V-count is a camera-based sensor as well. Just like the Brickstream 3D Gen 2 it is based on a stereo camera technique. It can count people in two directions at the same time, so it is suitable for determining the in- and outflow of a building. The accuracy that is promised by V-Count is 98%.

The main focus in the design of the V-Count 3D Aplha+ is to understand the way people move. So it is very suitable for retailers and other facilities where it is necessary to understand the people movement.

The V-Count 3D Alpha+ can count people real-time. So with this sensor it is possible to see the exact occupancy of TU Delft library if it is installed. It can also make reports of the peak hours and the off peak hours. Other features that this sensor has are calculating the conversion rate of customers, compare different locations where the sensor is placed. And it can count the number of groups that enter. However, all these features are not necessary for the TU Delft library.[6]

6.0.3. Irisys Gazelle 2

The Irisys Gazelle 2 is a people counter based on the infra-red technique. It is an overhead thermal-based sensor that detects the heat sources of the human body. This gives an advantage that this sensor is not influenced by the light level and can count in the dark. It can also count high crowds.

The Irisys Gazelle 2 can count people in multiple directions.[7].

6.0.4. FootfallCam 3D Plus

The FootfallCam 3D Plus is an overhead people counter that uses Camera and WIFI for detecting people movement. Just like the Brickstream and V-Count sensors it uses a stereo camera setup. Besides the in- and outflow movement, the FootfallCam 3D Plus can measure 6 other things:

- Dwell time: Thanks to the WIFI measurements the time a visitor stayed can be determined.
- Outside traffic: within a 100 metre radius the number of people passing can be determined
- Number of returning customers: thanks to the WIFI measurements the number of returning customers can be determined.
- Zone analytics: The number of visits in each zone of a building can be determined
- Traffic flow analytics: The traffic flow between the different zones can be determined.

The in- and outflow of people can be measured with and accuracy of at least 90%. The reporting of these values can be given in time frames of an hour, a day, or a week. So the real time occupancy cannot be determined with this sensor. [8]

6.0.5. Recommendation

In order to compare the different sensors some criteria that are important for the TU Delft library have to be determined. Those criteria are:

- **Criterion A**: The costs of the sensor.
- **Criterion B**: The accuracy of the sensor.
- **Criterion C**: Can the sensors give the real time information about the occupancy, inflow and outflow?
- **Criterion D**: Is it possible to use the sensor outside? And between what temperature range.

Table 6.1: Comparison table for the FILR Brickstream 3D Gen 2 and the V-Count 3D Alpha+.

Criterion	Brickstream	V-count
A	€1120.00 per piece and €14.10 per piece per month	€1200.00 per piece, monthly cost unknown
B	95%	98%
C	Yes	Yes
D	Yes, between 0 and 45 degrees Celcius	Yes, between +10 and 35 degrees Celsius

Table 6.2: Comparison table for the Irisys Gazelle 2 and the FootfallCam 3D Plus.

Criterion	Irisys	Footfallcam
A	Unknown	Unknown
B	99%	90%
C	Yes	No
D	No	No

Criterion A is not really usable for comparing the different sensors, since not all information about the purchase and the maintenance costs of all the sensors are available. A possible way to obtain these costs is by contacting the manufacturer or a supplier of the sensors. Criterion B is better to compare the different sensors. However, the accuracy information is provided by the manufacturer of the sensors itself and they have an interest in selling their own products. So it necessary to be careful with this information. One of the wishes of the TU Delft library is to know the real time occupancy of the building. So criterion C is good to determine if this is possible with each sensor. Criterion D is good to use in the comparison since it has been determined in chapter 5 that placing the sensors outside is the best place to measure the in- and outflow of the library.

By comparing the table is becomes clear that the FootfallCam 3D Plus is not recommended, since it has the lowest accuracy and it cannot give the real time in and outflow. If the TU Delft library chooses to place the new sensors outside the FILR Brickstream 3D Gen 2, which is delivered and installed by the same company as the current sensors are, is recommended. The V-Count 3D Alpha+ can be used outside as well. But only when the temperature is higher than +10 °Celsius. So this sensor is not really usable during the winter. If the TU Delft library chooses to place the sensors sensors that are recommended are the V-Count 3D Alpha+ and the Irisys Gazelle 2, because those sensors have a higher accuracy. However, the FILR Brickstream 3D Gen 2 is still a decent option, even if it is placed inside.

After investigating the different techniques and a few sensors that make use of these techniques a recommendation about the best sensor to use has been made. Keeping in mind the location that has been recommended in chapter 5 the FILR Brickstream 3D Gen 2 is recommended. However, if the TU Delft library chooses to place the sensors indoors, the V-Count 3D Alpha+ and the Irisys Gazelle 2 together with the FILR Brickstream 3D Gen 2 are recommended.

7 Analysing the data

The last part of the research is to determine the in- and outflow patterns over the course of a day. These patterns are compared between different days. These different days are normal days, days during the exam periods and holidays. Important to see is how the patterns are different between those days. Secondly the occupancy patterns between the different days are compared to each other.

The data that is used is the in- and outflow data of each hour of each day between the start of the academic year in September and the last day before the summer break in July for the years 2016/2017, 2017/2018 and 2018/2019 (up to and including May 31). The exam period days will be specified as the days during the exam period and the days in the lecture free week before the exam period when the TU Delft library has already the XXL opening schedule. During the XXL opening schedule the library is open until 2:00 instead of 0:00. The holidays will be specified as the days when there are no lectures, which includes the Christmas break, spring break, Kingsday, the Easter weekend, Ascension Day and Whit Monday. The normal days will be specified all other days in the year.

7.1. In- and outflow patterns

The first thing that is done is visualizing the in- and outflow patterns of the normal days in figure 7.1, exam periods in figure 7.2 and holidays in figure 7.3. These figures are the averages of the normal days, exam period days and holidays for all years together.

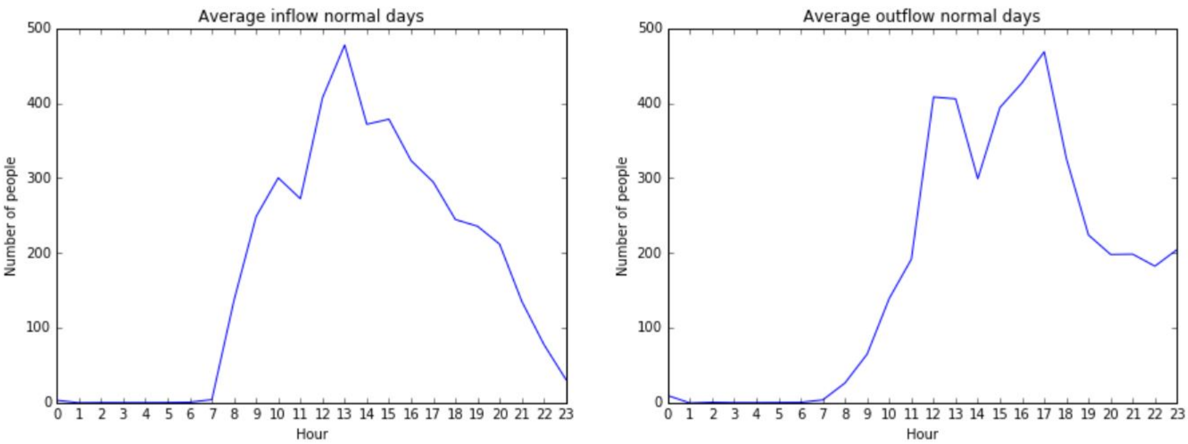


Figure 7.1: The average in- and outflow during normal days.

During a normal day the inflow increases rapidly over the morning with a small peak between 10:00 and 11:00 when the inflow is on average around the 300. So during this hour in the morning most students are woken up and enter the library. The second peak is larger and that peak is between 13:00 and 14:00. The average inflow during this hour is around 480 people. The reason for this peak is that most students had lunch and return to the library after lunch time. During the rest of the afternoon and evening the inflow decreases steadily.

The outflow during a normal day has two peaks. The first peak is between 12:00 and 14:00 and the average outflow is around 400 people per hour. The reason for this peak in outflow is that most people will have lunch during this time. So most people leave the library to have lunch somewhere else. The second peak in the outflow is larger and is at the end of the afternoon between 17:00 and 18:00. This is the time that most people will have dinner, so this is the reason that most people leave.

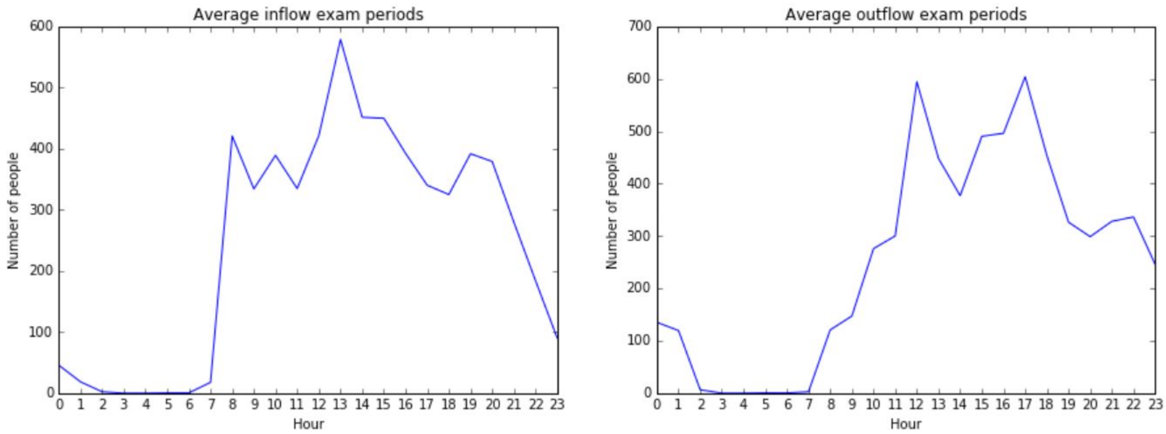


Figure 7.2: The average in- and outflow during exam period days.

During the exam period has the TU Delft library the XXL opening schedule. This means that the library is opened until 2:00 instead of 0:00. The inflow graph has three peaks now. The first peak is between 8:00 and 9:00. This is the opening time for the TU Delft library. So that means that students want to use the library earlier than during normal days. The second peak is just like normal days after lunch time between 13:00 and 14:00. So after having lunch more students come to the library. The third peak in the inflow graph is in the evening between 19:00 and 21:00. Since the TU Delft library is opened longer during the exam period, students enter the library after dinner to study during the evening.

The outflow graph has two similar peaks during day-time and one smaller peak in the evening. The first peak is between 12:00 and 13:00, when more students leave to have lunch. The second peak is at the end of the afternoon between 17:00 and 18:00 when more students leave to have dinner. The peak in the evening is between 22:00 and 23:00. So this is the time that most students who use the library in the evening leave. What can be seen in the outflow graph is that the library is used between 0:00 and 2:00, the hours that the library stay open longer during the exam period. So that means that the library is still used during this period.

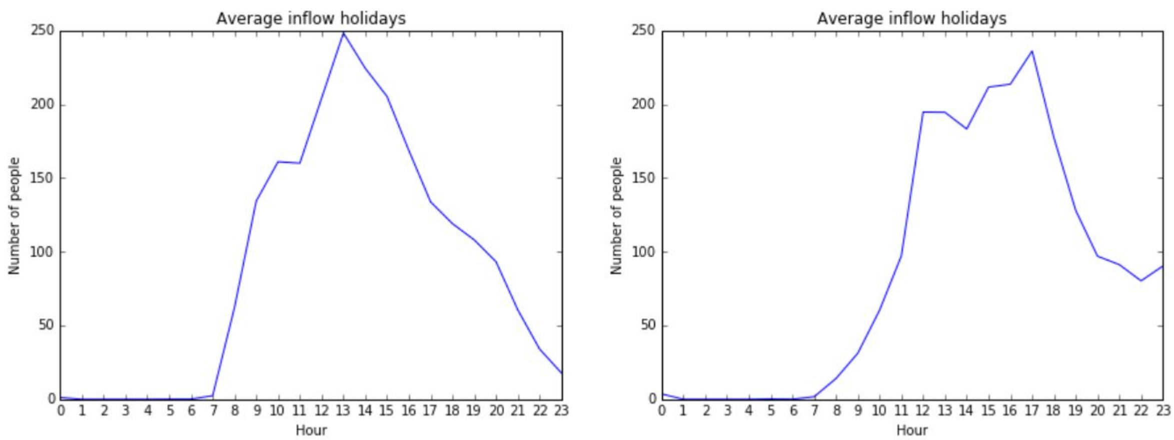


Figure 7.3: The average in- and outflow during holidays.

During the holidays there is not real peak in inflow during the morning. The inflow increases steadily towards it reaches the maximum between 13:00 and 14:00. So after lunch time the inflow is maximum. After this hour the inflow decreases steadily for the rest of the day. There is no peak in inflow during the evening.

The outflow during holidays has two peaks. The first is between 12:00 and 13:00 for the students who leave to have lunch. The second peak in outflow is between 17:00 and 18:00 when most students leave in order to have dinner.

7.2. Comparing different type of days

Now the in- and outflow patterns of the different kind of days are described they can be compared. The patterns have been plotted in figure 7.4.

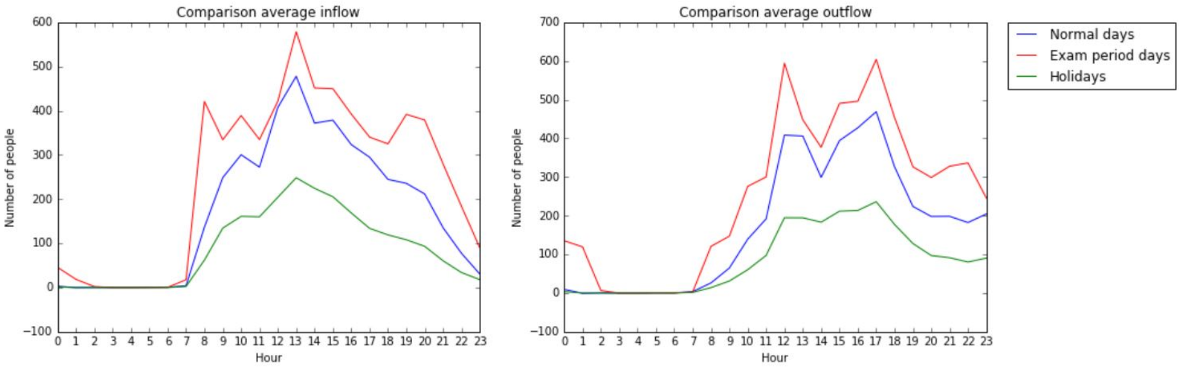


Figure 7.4: Comparison of the average in- and outflow.

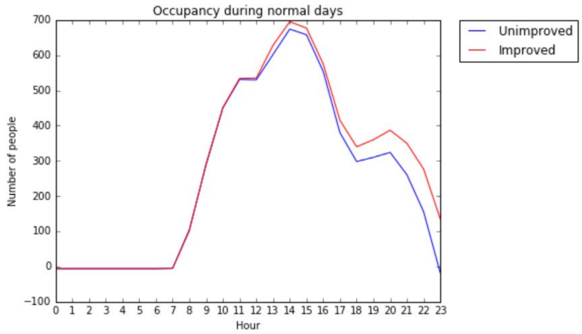
The first thing the can be concluded from figure 7.4 is that the in- and outflow is the highest during the exam periods. The in- and outflow is the lowest during the holidays. This is obvious because students have to study a lot more during the exam periods. The least work has to be done during the holidays and some students return back home during the holidays. so that is the reason for the lowest in- and outflow during the holidays.

What can be said about the average starting time of students on a day is that most students start the earliest during the exam period days. The first peak during exam periods is during the opening hour, between 8:00 and 9:00. The inflow in this hour is quite low for the normal days and the holidays. So that means that the library is occupied way earlier than during normal days and holidays. The reason for this is that students have to study a lot more during the exam period than during other days, so they start earlier. During the holidays most students start later than during the other days. The first real peak during the holidays is between 13:00 and 14:00.

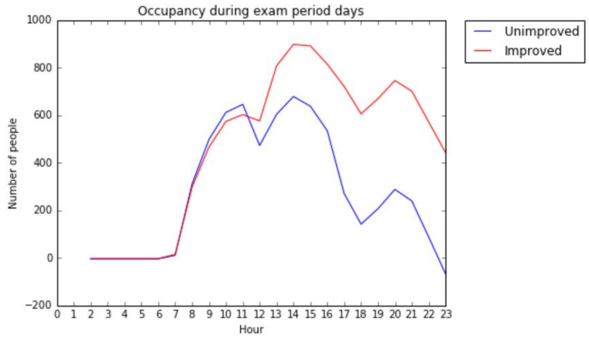
Another thing that can be seen in the in- and outflow patterns is that the library stays open longer during the exam periods and that the library is still used during these times. The evening inflow for the exam days is significantly higher than during the normal days and the holidays. And there is an outflow between 0:00 and 2:00 during the exam period days and there is no outflow between those hours during normal days and holidays.

7.3. Calculating Occupancy

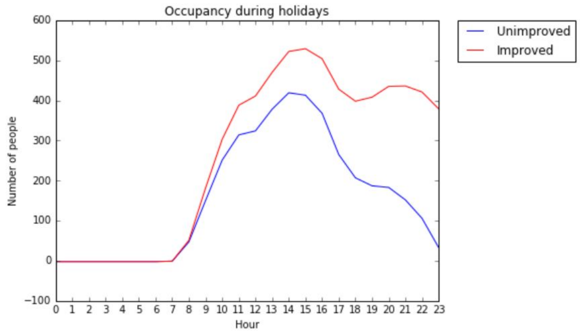
The most important use of the in- and outflow data is to calculate the occupancy of the TU Delft library. The graphs that show the occupancy in the TU Delft library for the different days are shown in figure 7.5. The blue line are the unimproved values measured by the sensor and the red line are the improved values. These values are improved with the functions that are developed in chapter 4.



(a) Normal days



(b) Exam period days



(c) Holidays

Figure 7.5: The measured occupancy and improved occupancy.

As can be seen in the figures the functions to improve the information derived from the sensor data do not really work for estimating the occupancy. Using these functions results in an occupancy at the end of the day that is way higher than zero. It should have been zero is the functions did work. Further explanation in this error will be discussed in the discussion in chapter 8.

So these graphs are not really useful to calculate the exact occupancy of the TU Delft library. However, they can still be used to determine the occupancy patterns over the day. The occupancy patterns will be described based on the unimproved data, because the occupancy at the end of the day is closer to zero than when the improved values are used. So the unimproved data seems more reliable.

During normal the occupancy of the building rises during the morning. When it is lunch time the occupancy stays about equal and rises again after lunch time. The occupancy the highest in the afternoon between 13:00 and 17:00. Before dinner time the occupancy drops and increases slightly in the evening. So that means that most students study in the library during the afternoon.

To determine the occupancy patterns for the exam period days is harder to describe. Both the improved as the unimproved lines seems to be unreliable. The unimproved line ends far below zero so that means that the building ends with a negative occupancy and that is impossible. However the improved data ends far higher than zero at the end of the day. so that means than when the library is closed there are still a lot of people in the building. So for the exam period days only the moments when there are peak can be described. However, the magnitude of the peak compared to each other cannot be determined based on this data. So three peaks in occupancy occur during the exam period days. The first is during the morning. Then when it is lunch time the occupancy drops a little and rises after lunch time during the afternoon between 13:00 and 17:00. After 17:00 the occupancy decreases, because more students will leave for dinner. The third peak in occupancy during the exam period days is in the evening when some students return to the library to study in the evening after dinner.

During the holidays the occupancy pattern of the morning is similar to the occupancy pattern of the normal days. So the occupancy rises steadily and the occupancy stays the same during the lunch break. The occupancy is the highest in the afternoon between 13:00 and 16:00 and after 16:00 the occupancy decreases. So during the holidays more students leave earlier than that they do during normal days and exam period days. The occupancy stays about the same between 19:00 and 21:00 and then the most students leave the library in the evening.

What can be concluded from comparing the in- and outflow and occupancy patterns is that the times that students have lunch and dinner is a factor that influences the in- and outflow of the library building. The in- and outflow of the library is the highest during the exam period and the lowest during the holidays. And during the exam period more students start earlier and more students stay until later in the library. During the holidays more students start later and leave earlier than normal days and exam period days.

8 Discussion

In this chapter, the issues that came up in the previous chapters will be discussed.

Number of measurements

The number of measurements that are needed can be determined with the following formula:

$$n = \frac{z^2 * \sigma^2}{d^2}$$

In which:
n: number of measurements needed
z: Z-score, this is 1.96 for a 95% confidence level
σ: the standard deviation

d is the value for the margin of error. This margin of error is chosen to be 5% in order to get reliable data. Then d can be calculated by:

$$d = 0.05 * mean$$

The mean and standard deviation is determined with the tools in Microsoft Excel. And then the number of measurements that are needed can be calculated. This has been done for the number of measurement errors and the percentage measurement errors. The results are shown in table 8.1.

Table 8.1: Calculating the number of measurements with a margin of error of error of 5%.

	Error in	Error out	Percentage error in	Percentage error out
Mean	25.2	61	7.6%	13.6%
St. Dev.	19.6	63.7	5.39%	9.84%
n measurements	933	1678	767	804

What can be seen in table 8.1 is that by choosing a margin of error of 5% the number of measurements that are needed are at least 767 for the inflow and using the percentage error. The number of measurement needed for the outflow values are even higher. The number of measurements that are done in this research are 14. This means that using this data will not result in reliable results.

If the margin of error is increased to 50% the number of measurements are shown in table 8.2. So even if the margin of error is 50%, which is too high already for reliable results, the number of measurements are not even sufficient for using the number of measurement errors for the outflow.

Table 8.2: Calculating the number of measurements with a margin of error of 50%

	Error in	Error out	Percentage error in	Percentage error out
Mean	25.2	61	7.6%	13.6%
St. Dev.	19.6	63.7	5.39%	9.84%
n measurements	9	17	8	8

So the conclusion is that the amount of data that is gathered is not enough to get a high reliability in the functions that are used to improve the information derived from the sensor measurement data. In a future research the number of counting sessions that are done must be higher to get more reliable data.

Times that counting sessions took place.

What the results of the counting sessions showed is that there is a relation between the different hours of the day and the number of measurement errors that occur. However, this relation cannot be determined, because not enough measurements have been done for this. Not all hours of the day are covered with measurements. So the relation between the time of the day the number of measurement could be a hypothesis for a future research.

Behaviour Patterns

As has been described at the end chapter4 Data Analysis a possible reason for the difference in measurement error between different hours is the behaviour patterns of people over the course of a day. So can be seen that the number of measurement errors is significantly higher between 17:00 and 18:00. This can be explained by the number of people that use the door towards the coffee corner. Another aspect is the fact that is was fairly busy in the entrance hall. Common behaviour that is noticed in the entrance hall is that people were waiting for each other to leave together. Some were standing underneath the coverage area of the sensors and other people had to walk around them. This kind of behaviour can also be responsible for different measurements errors in different hours. However, the exact behaviour patterns of people have not been studied during this research. So the things described above are some presumptions which could be investigated in a different research.

9
Conclusion

This chapter contains the conclusion of the research. The goal of the client, the TU Delft library is to get better insight in the in- and outflow of people in the library and to know the exact occupancy of the building. The current sensor setup is not accurate enough to provide the TU Delft library with reliable numbers.

First the current sensors have been researched and a method to improve the information derived from the sensor data. The best formula to use to improve the information derived from the inflow data of the sensors is:

$$I = X - (-0.000276X^2 + 0.171X - 16.5)/100 * X$$

I: Number of people walking into the library building
X: Number of inflow measurements done by the sensors

The best formula to use to improve the information derived from the outflow data is:

$$O = X - (4.82 * 10^{-25} * X^{9.55} + 28.3)$$

With:
O: Number of people walking out of the library building.
X: Number of outflow measurements done by the sensors

Due to a lack of measurements is the accuracy of these functions not really high as can be read in chapter 8, the discussion.

The recommended location to place the sensors is outside above the entrance doors. This is the best possible location to count the in- and outflow of people in the library building without frequent disturbances of people walking in different directions. However, new sensors are needed, because the current sensors cannot be placed outside. One of the other locations that can be used in order to save costs are the current location. What is recommended if this option is chosen is to close the door towards the coffee corner in order to reduce the different motions underneath the sensors. And the sensors should be moved closer towards the door and placed without an angle. The second option that can be used in order to save costs is placing the four current sensors above all entrances leading from the entrance hall and coffee corner into the main hall of the library. However, not the real in- and outflow of the library is measured if this option is chosen.

Some different sensors have been reviewed as well. The recommendation for the best sensor to use is the FILR Brickstream Gen 2. This is the sensor delivered and maintained by the company HS BIB, which also maintains the current sensors. This sensor has an accuracy of 95% and can give the real time in- and outflow and occupancy information. Another positive of this sensor is that it can be installed outside. So it can be used for the recommended location. Other sensors that are recommended are the V-Count 3D Alpha+ which has an accuracy of 98% and the Irisys Gazelle 2 which has an accuracy of 99%. However, it is not recommended to use these sensors outside.

The in- and outflow patterns have been determined as well with help of the in- and outflow data measured by the sensors. The patterns of the different kind of days have been compared, namely the normal days, exam period days and the holidays. What can be seen is that more students start earlier and stay longer in the library during the exam periods. During the holidays the library is less used. Most of the people who come during these days start later and end earlier than that they do during normal days and exam period days. The average in- and outflow patterns of these days are shown in figure 9.1.

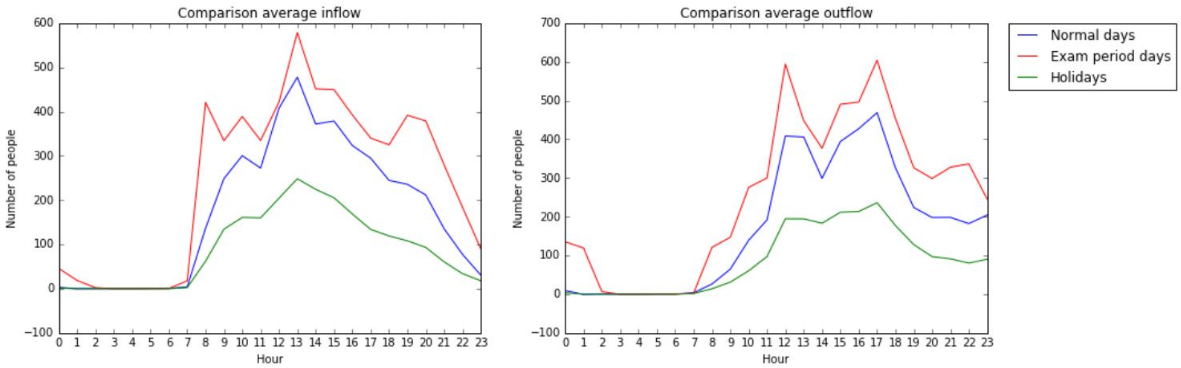


Figure 9.1: Comparison of the average in- and outflow.

It has been tried to calculate the occupancy of the TU Delft library as well. However, the correcting functions that have been determined do not work good enough to calculate the occupancy over the course of a day.

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A

Appendix

This appendix contains all the fitted plots that are discussed in chapter 4.

The inflow relations between the number of measurements done by the sensors and the percentage of measurement error:

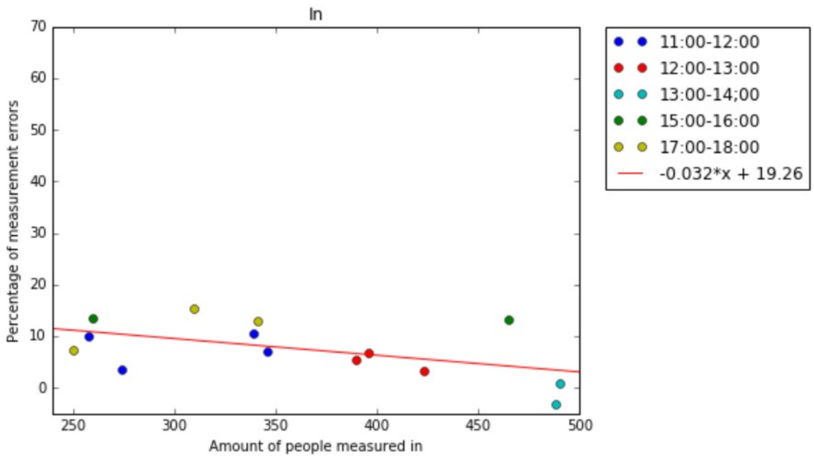

Figure A.1: R.M.S.E = 4.46 and R^2 = 0.261

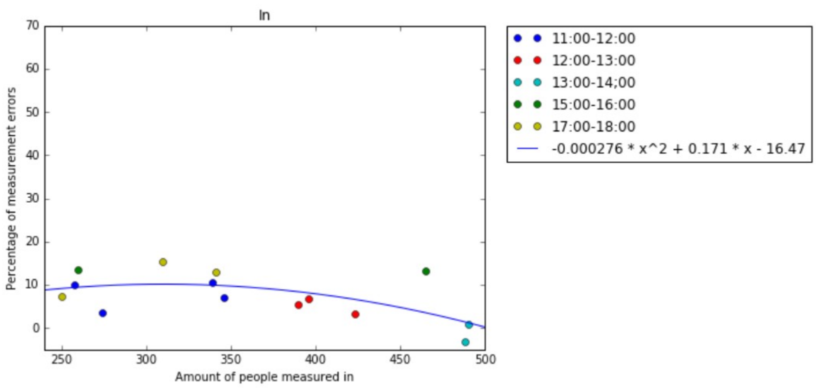

Figure A.2: R.M.S.E = 4.18 and R^2 = 0.352

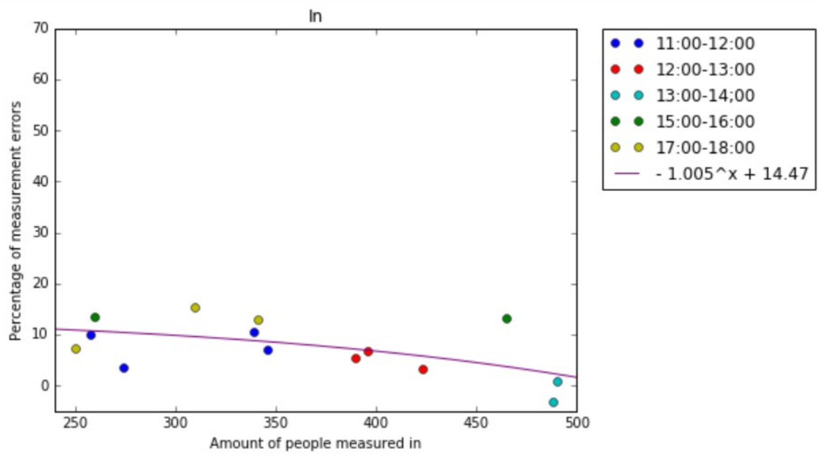

Figure A.3: R.M.S.E = 4.32 and R^2 = 0.308

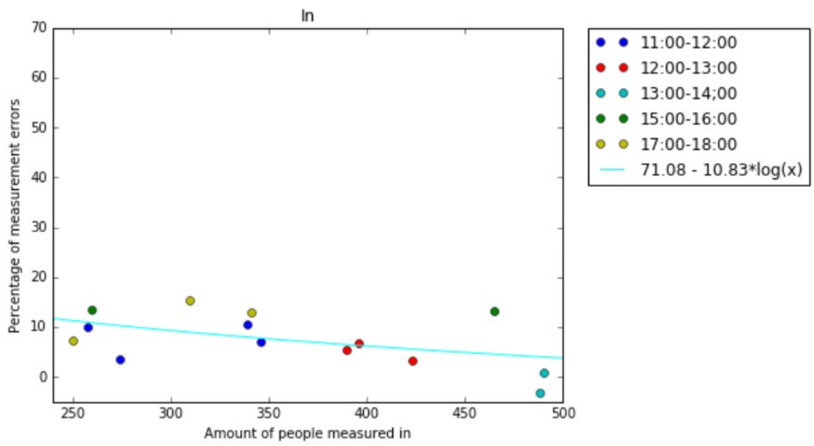

Figure A.4: R.M.S.E = 4.56 and R^2 = 0.230

The outflow relations between the number of measurements done by the sensors and the percentage of measurement error:

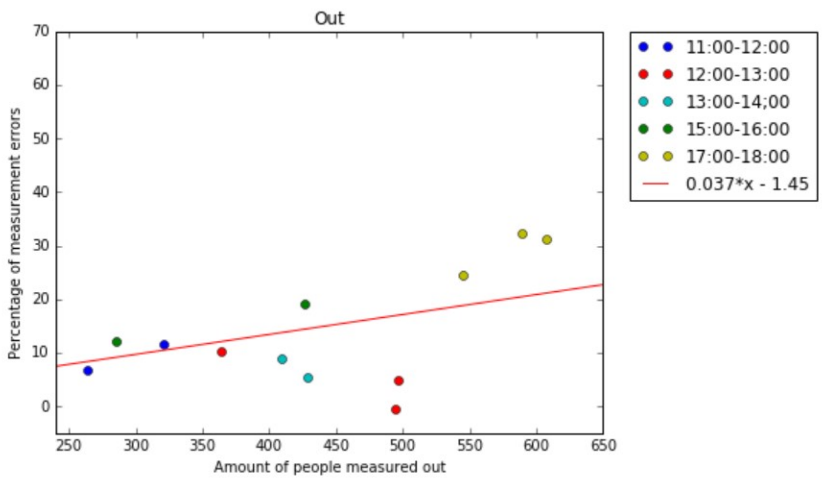

Figure A.5: R.M.S.E = 8.22 and R^2 = 0.249

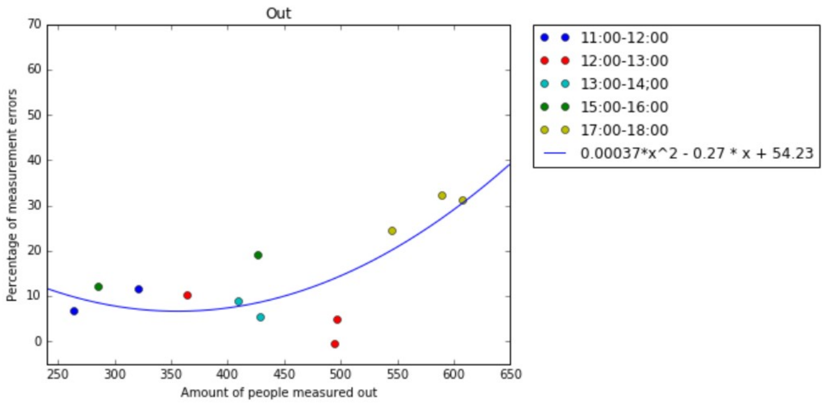

Figure A.6: R.M.S.E = 6.16 and R^2 = 0.578

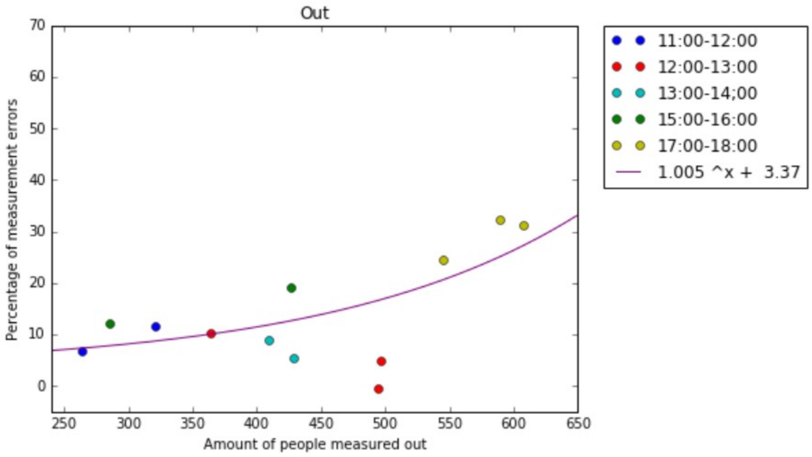

Figure A.7: R.M.S.E = 7.18 and R^2 = 0.426

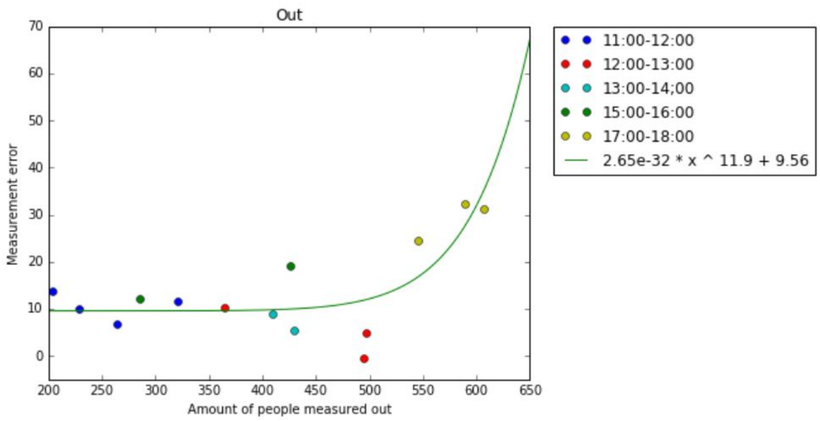

Figure A.8: R.M.S.E = 5.63 and R^2 = 0.647

The inflow relations between the number of measurements done by the sensors and the number of measurement errors:

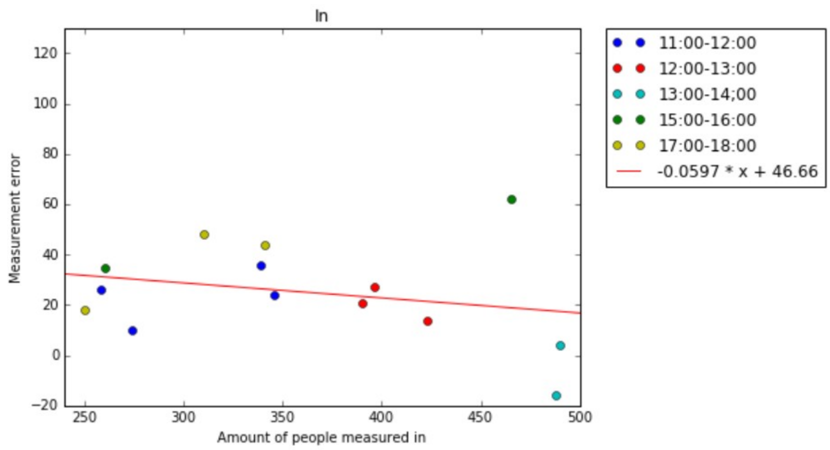

Figure A.9: R.M.S.E = 18.3 and R^2 = 0.0666

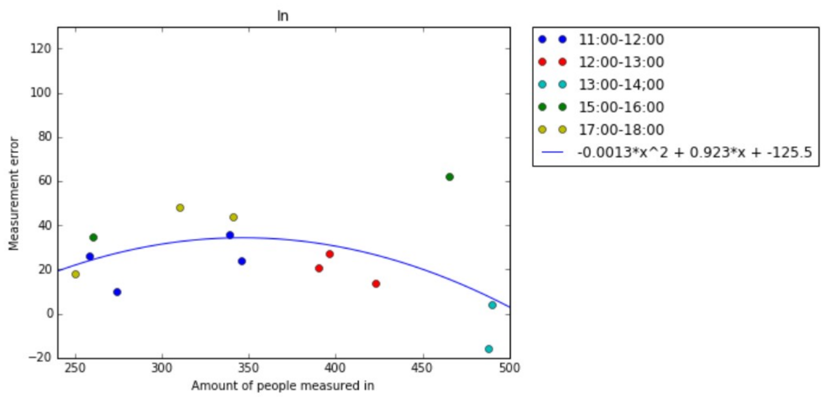

Figure A.10: R.M.S.E = 16.7 and R^2 = 0.226

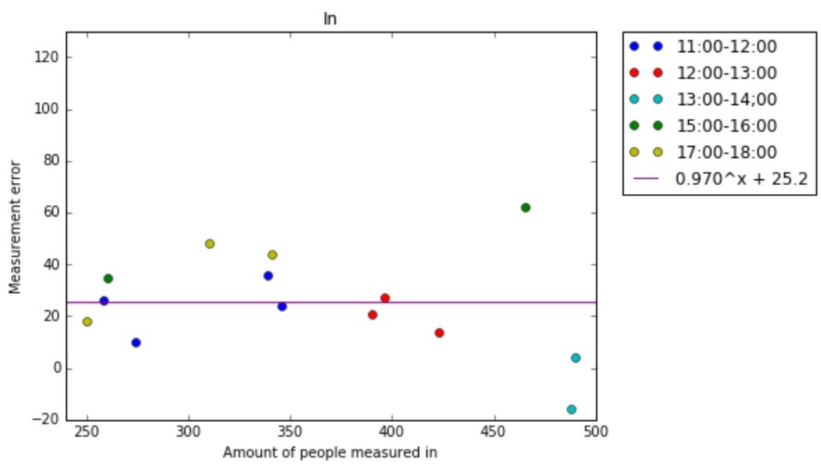

Figure A.11: R.M.S.E = 18.9 and R^2 = 2.59e-07

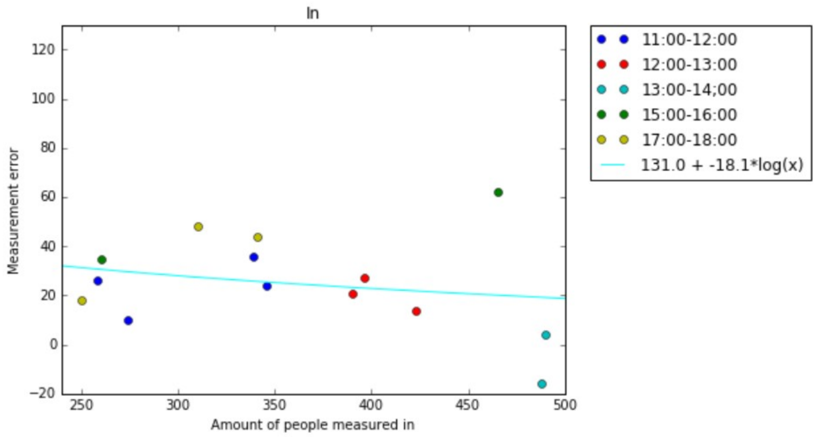

Figure A.12: R.M.S.E = 18.5 and R^2 = 0.0479

The outflow relations between the number of measurements done by the sensors and the number of measurement errors:

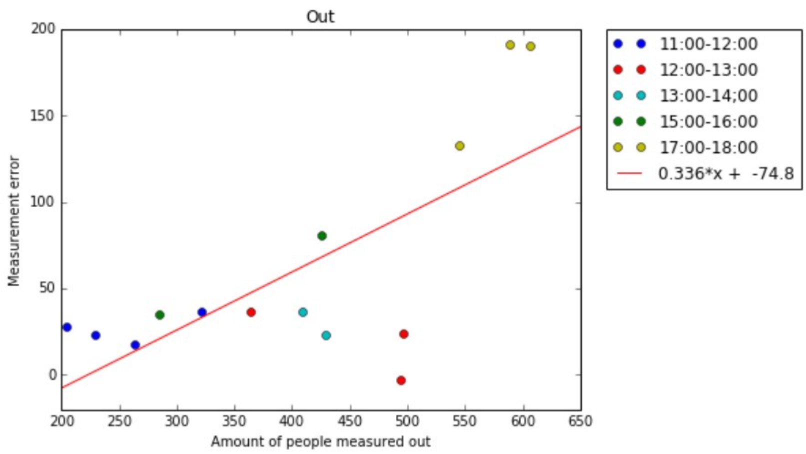

Figure A.13: R.M.S.E = 44.2 and R^2 = 0.482

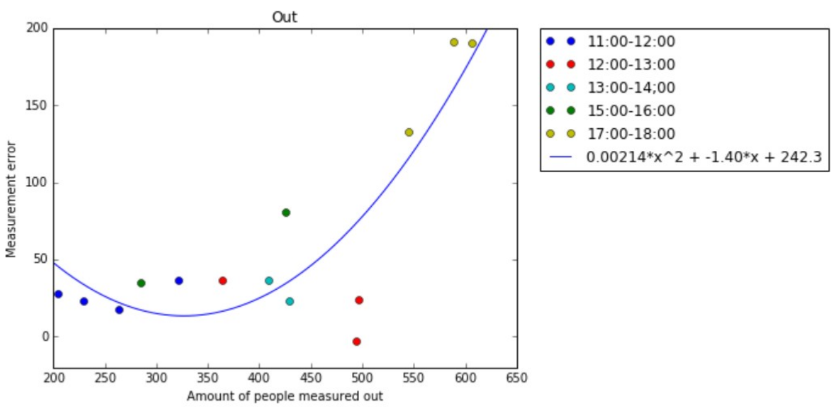

Figure A.14: R.M.S.E = 31.5 and R^2 = 0.736

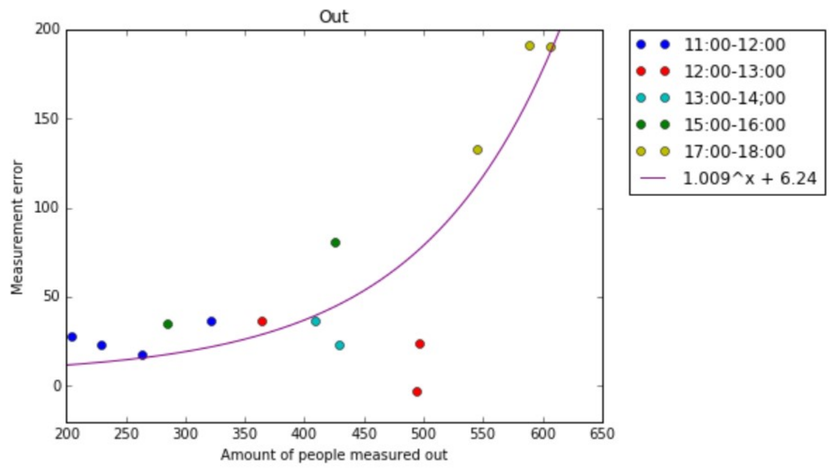

Figure A.15: R.M.S.E = 30.4 and R^2 = 0.755

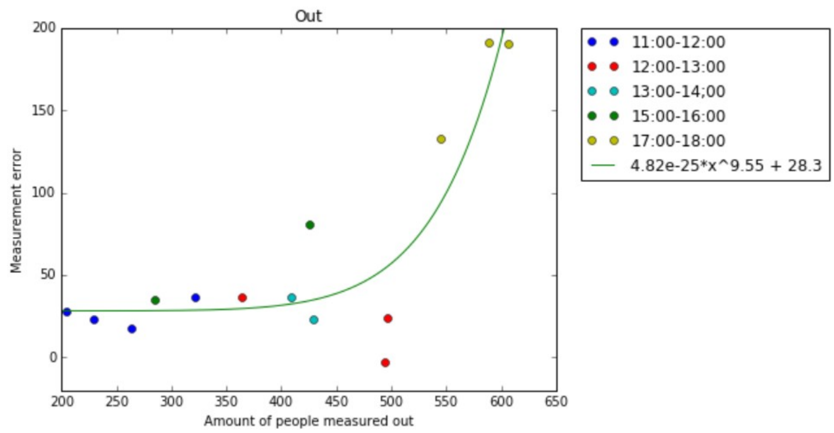

Figure A.16: R.M.S.E = 26.0 and R^2 = 0.820

B

Appendix

This appendix contains the literature study in the three most commonly used techniques in people counting sensors, which are Infra-red, camera and WIFI[3]. First the techniques will be described and then the advantages and disadvantages of each technique will be described.

Different techniques

The most commonly used techniques for people counting sensors are Infra-red, cameras and WIFI[3]. This section gives a general overview of how those techniques for counting people work.

Infra-red

The first generation of people counters are horizontal infra-red people counters[8]. Later more advanced people counters using infra red are developed. These are the overhead thermal people counters[9].

The most basic type of people counting sensor is the horizontal infrared beam counter[9], which can be seen in figure B.1. This sensor works by an infra-red beam that is casted from one side to the other side of a doorway. When a person walks through the door the beam will be broken and the person will be counted when this happens.

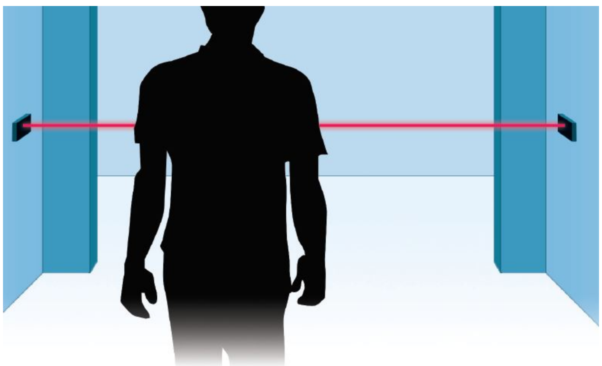

Figure B.1: The horizontal people counter[9].

Currently more advanced infra-red detection techniques are available. These are overhead sensors instead of horizontal sensors[9]. These sensors are thermal-based. That means that heat sources of the human body are detected by array sensors[8]. From this detected heat sources the motion of people can be determined. And then this motion can be used to determine the in- and outflow of a place with software.

The thermal-based sensors consists of an pyroelectric detector array which detects a change in temperature[**pyroelectric**].

Figure B.2 shows a picture of people walking underneath a thermal-based sensor on the left side. On the right the infra-red view is showed. Moving people are visible by the thermal sensor and are visualized as blobs. The algorithm for the post-processing recognizes these blobs as persons, based on their size. When people underneath the sensor stop walking, they will not be detected anymore, as the sensor only detects moving objects. The software will store the location, so it can pick up the person when it starts moving again. When people are walking close to each other, they will appear as one bigger blob. Because the algorithm knows the geometry of one person it can see the bigger blob as two persons[10].

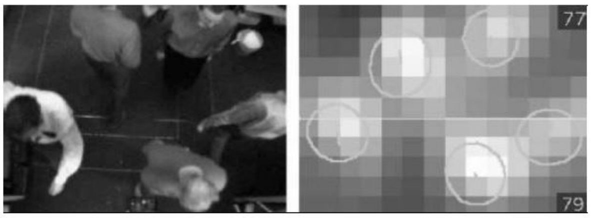

Figure B.2: Left: visible image of people underneath the sensor. Right: the infra-red view.[10]

To use the thermal sensors for people counting, some virtual structures have to be implemented. These can be a line or a box. When people cross the line or walk from one side of the box to the other, they can be counted by the algorithm. This makes it possible for the sensors to count the in- and outflow of people in the location where it is installed.

Cameras

One of the techniques for the counting of people is the use of one or more cameras and software to determine the quantity and direction of people flow. First, a commonly used method to detect moving objects is described and after that the algorithms to count the people are described.

A commonly used method to detect moving objects in a static camera is background subtraction[11]. The most basic form of background subtraction is comparing the current frame produced by the camera to a reference frame. The reference frame is the frame with only the background on it without any moving objects. This reference frame must be updated regularly to account for the varying luminance conditions and geometry settings. The moving objects and persons can be detected by the difference in the current frame and the reference frame. Some of the more advanced methods for background subtractions exist as well[11]. The exact way those methods work is not relevant for comparing different sensors, so it will not be further elaborated.

After the moving objects have been detected they need to be counted based on their direction. A simple method to count the people is by using a single reference line. The current sensors, the CC MED, use this method for counting people[2]. When a person crosses the line in the in direction, it will be added to the inflow. The same is done for the outflow when the person crosses the line in the out direction[12].

Some systems use two lines to count the in- and outflow of people. One of the lines only count the people heading out of an area. The other line is placed a little further into the area and counts only the number of people heading into the area. This is done to prevent the counts of people who make a u-turn at the entrance and decide not to go in[13].

A more advanced method for counting people using a video system is proposed by J. Barandiaran, B. Murguia and J. Boto[14]. It uses multiple lines to count people in two directions. All those lines count the people passing it separately. In the final step of this algorithm the results of the different lines are combined. The result of the whole system is equal to the result that is counted by most of the lines.

WIFI

Wifi counting can be done in multiple ways. One of those is by making use of devices that are connected to a WIFI network[15] and another way is without tracking devices[16].

J. Kalikova and J. Krcal propose a method for counting people by using the amount of devices that are connected to the WIFI network[17]. This method uses an access point that broadcasts a wireless network. Devices like smartphones search for available networks. The software used in the WIFI tracker gathers information of the searching devices. This information includes the MAC address (Media Access Control Address) and the RSSI (Received Signal Strength Indication). The software uses this information to determine how many people are inside of a determined area.

The second method where WIFI can be used to determine the occupancy and in- and outflow of people is without tracking devices. A method to do this has been proposed by S. Depatla, A. Muralidhan and Y. Mostofi[16]. This method can be executed with the use of two devices: one WIFI transmitter and one WIFI receiver. Two effects will interfere the WIFI signal, namely blocking the Line of sight and scattering effects. When a person is blocking the line of sight between the WIFI-signal transmitter and receiver, the received signal strength decreases. And when a person is walking outside of the line of sight it bounces off a part of the signal towards the wifi receiver. This will increase the received WIFI signal. A visualization of the blocking the line of sight and scattering effects can be seen in figure B.3. It can be seen that people standing in the line of sight of the WIFI signal will block it and the people standing on differenct places will increase the signal due to the multi-path of the signal.

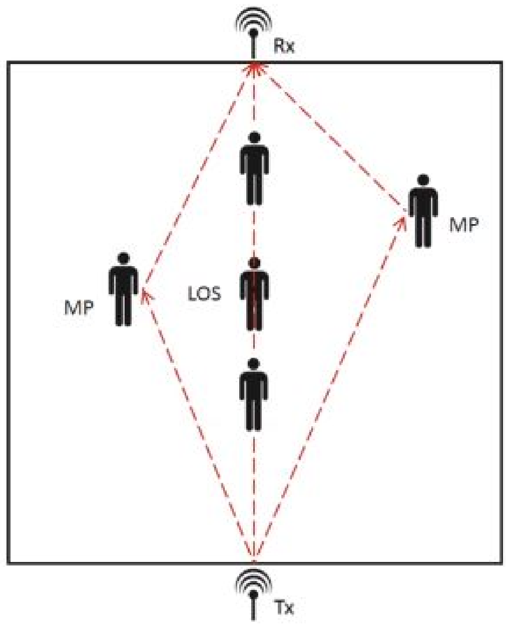

Figure B.3: Visualization of blocking line of sight and scattering effects.[18] LOS: line of sight, MP:multi-path

In the next step a probability density function is created with the effects of blocking the line of sight, scattering effects and static objects kept in mind. Based on this function the occupancy of a room can be determined. Experiments have been done with a maximum of 9 people in a location. It has been performed outdoor and indoor. As can be seen in figure B.4 the accuracy is higher when this method is used outside.

Number of People in the Area	1	3	5	7	9
Estimated Number of People	1	3	4	7	8

(a) Results of experiment outdoor

Number of people in the Area	1	3	5	7	9
Estimated Number of People	2	3	8	10	11

(b) Results of experiment indoor

Figure B.4: Results of the experiment.

This method has been further elaborated by Y. Yang, J. Cao, X. Liu and X. Liu[19]. This makes it able to count people entering and leaving a room, even if they carry a device emitting a WIFI signal. The goal when designing this method was that the people counter should be: non-intrusive, accurate and low-cost. Detecting people moving through a doorway is done by analysing the WIFI signal and see how the interference in the signal is. The signal emitted by the carried WIFI device, like a smartphone, should be filtered out of the data. In the end the accuracy of this method is between 92% and 95%.

Advantages and disadvantages of the three techniques

Now the different techniques for people counting senors have been described, it is time to discuss the advantages and disadvantages of each technique. After this has been done the techniques can be compared to each other.

Infra-red

The first thing that has been described in subsection B was the horizontal infra-red beam counter.

Table B.1: The advantages and disadvantages of the horizontal infra-red people counter.

Advantages	Disadvantages
Low costs	Very low accuracy
Quick installation	Cannot measure multidirectional
	Cannot cover wide entrances
	Cannot detect people walking side by side
	Cannot be connected to network, so manual reading out
	Accuracy affected by direct sunlight.

The main advantage of this type of sensor is that the costs are low[9]. This makes it a good starting point for businesses that want to try out with customer counting. Another advantage is that the installation is relatively quick, because those sensors are placed in the door frame, instead of the ceiling.

The biggest disadvantage is the accuracy of the sensors. That is because the sensor struggles when multiple people walk though it at the same time. It can only detect the number of time the beam gets broken. So if the beam stays broken when multiple people walk through it, the sensor counts it as one. A second disadvantage is that it cannot measure multidirectional people motions. So if the building does not have a separate entrance and exit, they in- and outflow cannot be measured. Another disadvantage is that the sensors cannot measure accurate in wide entrances. The accuracy decreases when the entrance is wider than 3 metres.[9] The sensors accuracy is reduced b direct sunlight.

Another type of infra-red sensor that is described in subsection B where the sensors that detects the thermal energy of people passing it.

Advantages	Disadvantages
Decent accuracy between 80% and 95%	Higher costs
Can count multidirectional	Cannot distinguish children and adults
Accuracy not reduced by the light level	Cannot cover wide entrances
	Accuracy can be influenced by temperature

Table B.2: The advantages and disadvantages of the overhead thermal people counter.

An advantage of this type of sensor is that it can count multidirectional people motions. These sensors can be placed in wider entrances without a decrease in accuracy. The overall accuracy is around 95%.[9]

A disadvantage of these sensors is that the costs are higher than the horizontal sensors. Another disadvantage is that it cannot make a difference between children and adults.

Camera

Table B.3: The advantages and disadvantages of the overhead camera-based people counter.

Advantages	Disadvantages
Decent accuracy 90-95%	Higher costs
Can count multidirectional	Requires more effort to install and calibrate
Can cover wide entrances with multiple units	Can be effected by shadow, low light and changing background
Software ca be updated if better is available	
Can distinguish children and adults	

Camera-based sensors have multiple advantages. These sensors can cover wide areas when multiple units are used together. Another positive side of the camera-based sensors is that a major part of the sensors is based on software and if this has some flaws, it can easily be updated. The third advantage of the camera based sensors is that it can distinguish children from adults.[9].

The camera-based sensors have some disadvantages as well. One of those is that the camera-based sensors have higher costs. Another downside is that the camera-based sensors require more effort in installing than the infra-red sensors. The third disadvantage is that the counts of the camera-base sensors can be effected shadows, changing background and changing light levels.

Wifi

Table B.4: The advantages and disadvantages of the horizontal WIFI people counter that detects devices.

Advantages	Disadvantages
Accuracy is not reduced by light level, temperature	Reduced accuracy due to dependency of people carrying a device.
Can detect customer returning behaviour	Tracking devices may raise privacy concerns

The WIFI sensors that detect devices connected to the WIFI network has as advantage that the accuracy is not reduced by the light level and temperature. Another advantage is that is can detect the returning behaviour of people.[17]

It has some disadvantages as well. The main disadvantage of this type of WIFI people counting is that it is reliable of people carrying a device. If people don't they will not be counted. Another disadvantage is that is can raise privacy concerns since they sensor detects people their devices. Although the identity of the people is not known. These sensors can measure the occupancy but it cannot measure the exact in- and outflow.[17]

Table B.5: The advantages and disadvantages of the horizontal infra-red people counter.

Advantages	Disadvantages
No privacy infringement	Can be disturbed by other devices
Accuracy is not reduced by light level, temperature	
Could reach an accuracy of about 86%	
Can count multidirectional.	

The WIFI detection method that used the WIFI signal to identify humans has as advantage that there are no privacy concerns, since the WIFI signal is not used to detect devices. The accuracy is not reduced by light level and temperature. It can count multidirectional and could reach an accuracy of 86%[19].

It has as disadvantage that the accuracy can be reduced, because of disturbing signals emitted by other devices.

Comparison

To compare the different advantages and disadvantages of the different people counting techniques a comparison table has been made. The four different point on which the techniques are compared are:

- **A**: The accuracy is reduced by:
- **B**: Can it count multidirectional?
- **C**: Can it cover wide entrances?
- **D**: Are there privacy concerns?

Table B.6: comparison table for the Infra-red and video people counting techniques.

	Horizontal I.R.	Overhead thermal	Video
A	Direct sunlight	Temperature	shadow, low light and changing background
B	No	Yes	Yes
C	No	Multiple units can work together	Yes and multiple units can work together
D	No concerns	No concerns	No real privacy issues

Table B.7: Comparison table for the WIFI people counting techniques

	WIFI 1	WIFI 2
A	People not having a device of multiple devices	Other devices
B	No real in- or outflow is counted, only the occupancy is measured.	Yes
C	-	Yes
D	Yes	No concerns

What can be concluded is that the overhead thermal and video-based sensors are the most suitable. The WIFI counters are not the most suitable sensors since they can be influenced by devices and most students that come in the library have a smartphone and use their laptop. This makes it complicated to exactly count the occupancy in the library with the use of WIFI.

The horizontal Infra-red sensors have a very low accuracy so this is not a suitable technique either. That leaves the overhead thermal and video-based sensors as the most suitable.