Design of Data Acquisition Solution for Prognostics & Health Management in LED Screens

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Abstract

LED screens are often used in Road side advertisement screens, they last long and can withstand the harsh outside environment. Even though these screens are generally well built, this doesn't mean they don't need to be repaired. This paper aims to research how Prognostics and Health Management (PHM) can be implemented in large scale LED screens, to go from reactive maintenance to preventive maintenance. Mainly maintenance records of these screens are used to analyse the kind of failure modes that occur in these screen and whether they are suitable for PHM. These screens turned out to mainly have issues with corrosion on the cooling fan of the power supplies and water damage in the LED tiles. The internal diagnostics system is unfortunately not very expandable, causing possibilities to be limited in terms of monitoring important parameters.

1. Introduction

LED screens are being used more and more due to their long life and low power consumption. The scale of these LED screens has been expanded further into the consumer desktop screens, but also into the large scale advertisement screens. Most of these large scale advertising screens in the Netherlands are developed by Hecla Professional BV. At the moment Hecla uses a system of webcams to monitor the performance of these LED screens at a distance. Their current maintenance system is based on reactive maintenance, someone from Hecla sees that a screen is broken or a client calls for repair. And after the failure has been detected an engineer goes onsite to repair the screen. This means that the repairs only take place after the screen is already broken, causing the screen to be malfunctioning for at least a few hours. In turn this means that the advertisements that are on the screen are not shown for a while, creating less publicity for the client. Therefore the downtime of the screens should be kept as low as possible, and to achieve that, Hecla would like to improve the way in which the screens are being monitored and repaired. A new system should be able to accurately predict imminent failure, in order to minimize the downtime of the screens even further. Sucht that the screens can be repaired and maintenance can be performed before the failure has even occured. As a first step towards this goal, this research aims to analyse the possibilities for applying Prognostics and Health Management in these LED screens.

The research question of this bachelor thesis is: **How can imminent failure of LED screens be detected and predicted as a first step towards PHM?** PHM is an abbreviation for Prognostics & Health Management, often used in the field of service prediction as an overarching term. This graduation project will explore the first steps towards implementing a PHM solution in Hecla Professional BV's LED screens. The goal is to provide Hecla with advice and a plan for what is needed before implementation of PHM is possible in their applications and where possible a prototype or proof of concept of such a system will be included.

The report will start with the state-of-the-art research of “Prognostics and Health Management” (PHM) of electronics, after which the electronics system of the screens will be briefly introduced. The main failure modes of the screens will consecutively be determined and the feasibility of monitoring these different failure points will be discussed. The main part of the paper will dive deeper into one of these failure modes, aiming to design a means of monitoring this mechanism. This part will discuss three main topics; parameters of interest, in situ measuring options and the actual design of the data acquisition solution. For this solution, the boundary conditions and requirements will be discussed and the proposed integration of such a system will be analysed.

2. State of the Art review

The IEEE standards committee defines Prognostics and Health Management as follows:

- Prognostics: “The process of predicting an object system’s RUL by predicting the progression of a fault given the current degree of degradation, the load history, and the anticipated future operational and environmental conditions to estimate the time at which the object system will no longer perform its intended function within the desired specifications.”[1] Where RUL refers to “Remaining Useful Life”.
- Health Management: “The process of decision-making and implementation of actions based on the estimate of the state of health derived from health monitoring and expected future use of the system.” [1]

Liu et al. [2] point out that PHM has been actively used over the past few decades, but that in the last few years the number of research, patents and books has increased exponentially. Around 2008 the number of patents in PHM in general started growing very rapidly and following around 2012 the number of patents in PHM for electrical systems took of in big numbers. PHM has sparked the interest of more and more electrical engineers as it enables them to assess the reliability and performance of a system *in situ*. Whereas before, routine measurements and lifetime testing was done in a lab. PHM gives the opportunity to monitor devices realtime, at a distance and in their normal operating environment.

Methods for PHM in Electronics

According to Pecht et al. [3], there are three approaches to PHM, Model-based approach, Data-driven Prognostics approach or a hybrid of the two. In Model-based systems, a Physics of Failure (PoF) approach is used to analyse the failure mechanisms and combines that information with other data to construct a detailed Failure Modes, Mechanisms and Effects Analysis (FMMEA). FMMEA is an important part in the development of a specific PHM system, as it gives insight into what parameters are of interest. Data-Driven PHM however, does not start by analyzing which parameters to monitor, but instead aims to globally monitor the main parameters. The assumption is then made that the statistical characteristics of the system data should be relatively constant unless failure occurs.

Zhang et al. [4] propose a four step plan to constructing a prognostics system which is visualised in Figure 1 as a flowchart. Their approach is aimed specifically at power supplies, but is general enough to be applied to other systems. The flowchart starts with Precursor Parameter Identification, which aims to identify the measurable parameters in the system that can indicate failure. An important part in prognostics, also mentioned by Pecht et al. is making a correct model. In this case no complete model is made, but a baseline is established and validated. The prognostics system can then monitor whether the system is deviating significantly from the baseline.

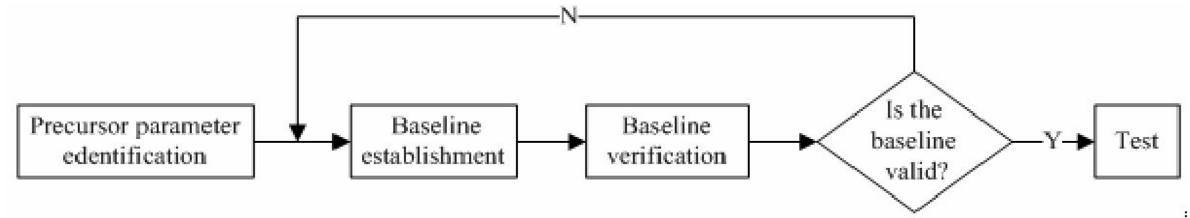

Fig. 1: PHM baseline creation approach [4]

Pecht [5] describes three methods of assessing the health status of a system, as a first, life cycle loads are introduced. "The life-cycle loads are monitored in situ, and used in conjunction with PoF- based damage models to assess the degradation due to cumulative load exposures." [5]. Life cycle loading usually employs more environmental and derivate measurements like temperature, humidity or vibration. The second method proposed by Pecht [5] involves adding a canary device to the system that has the same failure mechanism. The name is derived from when mine workers used canaries (the bird) as an indication method for the air quality in the mine, the canary is more sensitive to bad air quality than humans, so when the canary died, the mineworkers knew that it was bad. In the same way, the canary device as prognostic measure should show failure earlier than the actual device, indicating to the PHM system that failure of the actual device is imminent. The third method proposed in this paper is similar to the model-based approach mentioned before.

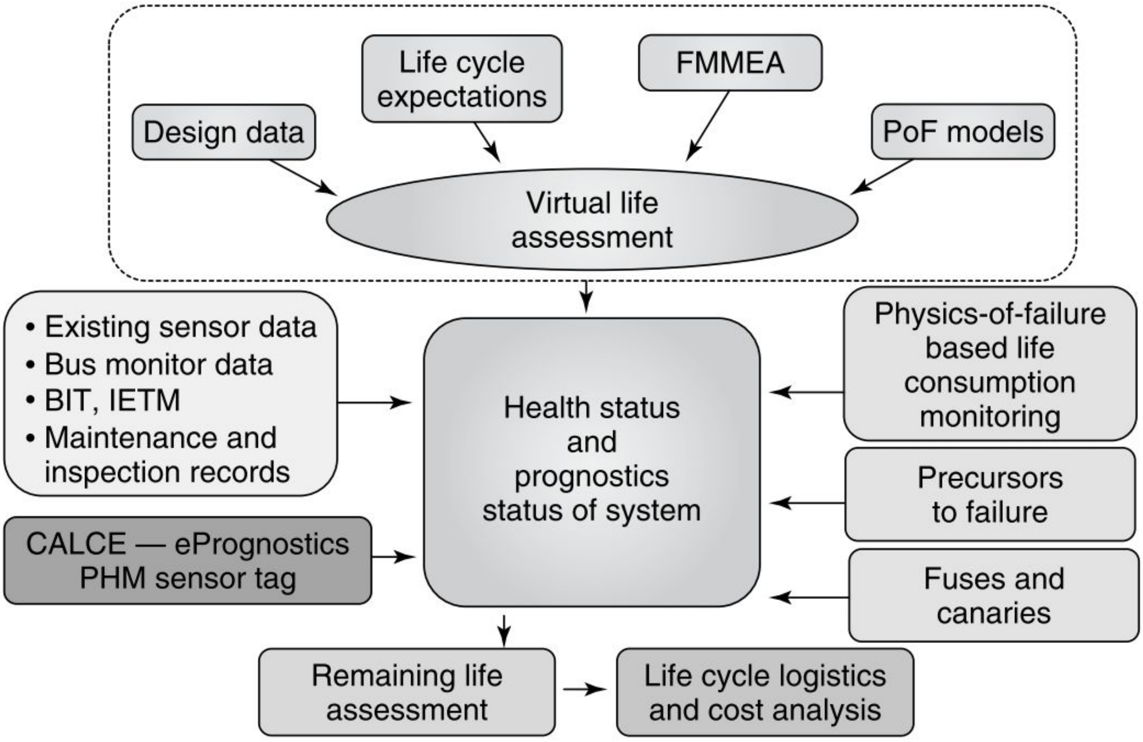

Fig. 2: schematic view of involved mechanisms in PHM [5]

In Figure 2 a schematic overview of the “anatomy” of a PHM system is displayed, most of the approaches discussed are on the right side like life consumption monitoring, canaries and precursors to failure. These are live monitoring approaches, whereas the 4 points at the top of the schematic are approaches to constructing a model of the component of interest. Failure Modes, Mechanisms and Effects Analysis, Physics of Failure amongst others are important tools in constructing a model of the failure. Well executed FMMEA and PoF contribute to determining which parameters of the system are to be monitored and how these parameters can be measured.

3. Methodology

In the State of the Art multiple methods have been proposed to develop a PHM system. In this research mostly the method depicted in figure 2 will be used. As this system will be applied to similar equipment, all installed by the same party, namely Hecla, a lot of information should be available at this party. This information needs to be gathered and analysed. Depending on the amount of data available, different parts of the analysis can be done. This analysis should preferably include amongst others the following parts:

- Analysis of what parts are more prone to failure than others
- Failure Modes, Mechanisms and Effects Analysis
- Physics of Failure analysis & model creation
- Precursor Parameter Extraction

Depending on the data available, different parts of the failure model can be established and baselines and thresholds for failure detection and/or prediction can be set. Probably the most basic documentation available is documentation about maintenance and repairs. From this documentation the most prevalent failure modes can probably be extracted. In addition to documentation, employees of Hecla can be asked for information as they probably have a good idea of what the biggest problems in the LED screens are. Once there is a reasonable idea of what the most vulnerable parts in the LED screens are, these should be discussed with employees of Hecla to assess which of these failures are most useful and feasible to perform prognostics and health management on.

An accurate physics of failure model should be established for the most prevalent failure modes. This is usually done with the help of a Failure Modes, Mechanisms and Effects Analysis, to perform this elaborately and accurately, more information is needed. Logs of sensor values within the LED screen are very useful for this. Next to system parameters, usually also environmental parameters are taken into account, especially since these screens are located in outside environments, this can be of interest.

If sensor logs and failure documentation is available, these can be linked and the sensor values before the failure can be analysed. This can be used to analyse whether there are precursors in these measurements that can be used to predict and detect failure.

The research question is: **How can imminent failure of LED screens be detected and predicted as a first step towards PHM?** This question can be answered in different ways, either by proposing a hardware design for the implementation of a system that has this functionality. Otherwise, a set of advices and requirements for implementation can be proposed that are needed before PHM can be implemented. The direction to go in will depend on the findings in the following sections.

4. LED Screen

This Chapter will introduce the electrical system of the LED screens, the design data of the system which according to Pecht [5] can be used as a tool for the virtual life assessment (figure 2). The specific screens of interest for this graduation assignment are the large LED screens used by Interbest BV along Dutch highways. The screens are produced by Hecla Professional BV, who are the client in this assignment.

Along the highways in the Netherlands, 14 different screens are placed on different locations. The biggest screen by Hecla is around 110m^2, a screen is made up of multiple panels of a little less than 0.8847 square meter. The content of the LED screens in sent through a normal HDMI input, which arrives at a processor, the processor translates this into a signal that is sent serially through a coax cable to the different panels. Next to the processor there is an AMX or Crestron, this part in combination with an LDR in the automatic brightness control, regulate the brightness of the screen making sure drivers on the highway aren't blinded by the screen. Each panel contains an NPC (New Panel Controller) board, this splits the signal from the coax cable into 4x6 different parts and distributes them over the LED tiles. Connected to the NPC, the EMB or Environmental Management Board is found, this controls the fan power and monitors the temperature in the panel. The screens of course need power, this is supplied by three power supply units in each panel. One power supply for red, one for green and blue of the left half of the panel and one for green and blue of the right half of the screen. See figure 3 below for a schematic representation of the LED screen or figure 1 and 2 of Appendix A for an enlarged version.

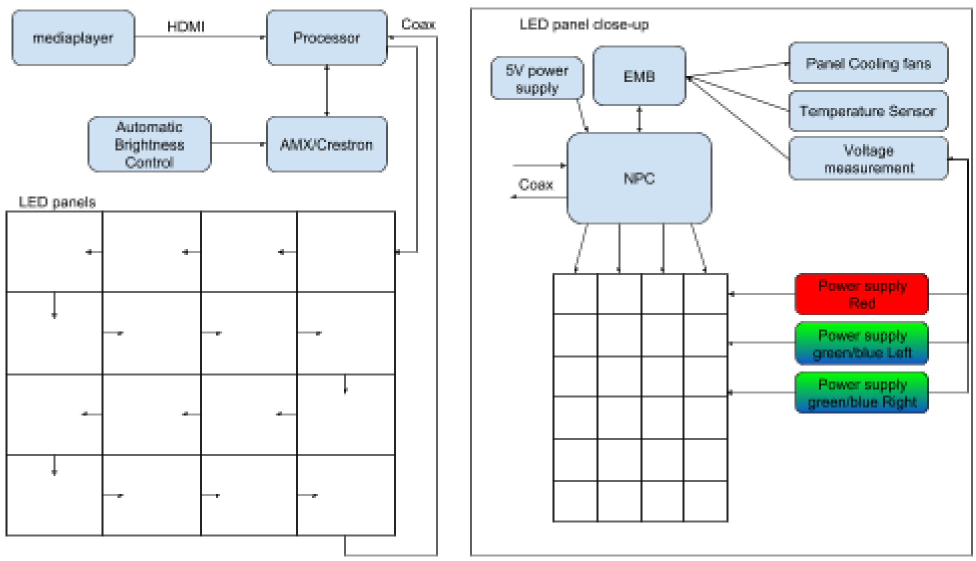

Fig. 3: schematic representation of the electronic system of an LED screen (detailed version in appendix A)

In the right part of the schematic in figure three a close up of one LED panel can be seen, each panel contains an EMB or Environmental Management Board. This EMB is connected to the cooling fans of the panel, the temperature sensor in the panel and contains the hardware for the voltage monitoring of the power supplies. The measurements of the EMB can be retrieved from the screens over the air with a software package from the manufacturer,

An example of such a panel can be seen in figure 4, this is a panel with a surface of 108m^2, 12m wide and 9m high. This screen consists of 14 x 18 = 112 panels and is placed at the A12/A27 highway near Schiphol.

Fig. 4: Interbest LED screen by Hecla BV along the highway near Schiphol International Airport [6]

5. Maintenance Records

As one of the first steps towards prognostics & health management, an analysis should be done to find out what failure modes exist in the system. In figure 2 it can be seen that maintenance records and historical information about failure are important in developing a prognostics system [5]. Therefore the maintenance records are examined and classified. Hecla has kept track of the repairs and maintenance it executes on these LED screens. Using documentation of all the LED screens between September 2014 and April 2018, the LED screens, and their weak points will be analysed. The documentation consists of 444 separate, unique repair and/or maintenance instances, ranging from single worn out pixels to whole screens not functioning. These repair instances have been categorized and listed below, with their absolute and relative occurrence rates.

Table I: occurence of different modes of failure in the LED screens between September 2014 and April 2018

component	number of occurrences	percentage of failures	Relative occurrence	detectability	Predict-ability	severity
Tile Defect	166	34.66%	~0.5%	Medium	Low	4
Power Supply Failure	127	26.56%	~3.0%	High	High	4
Undetermined	60	12.53%	-	-	-	-
Other	26	5.43%	-	-	-	1
Maintenance	23	4.80%	-	-	-	1
NPC	23	4.80%	~1.6%	Medium	Low	4
Brightness Control	22	4.59%	~157% *	Medium	Low	5

AMX	14	2.92%	~100% *	Low	Low	3
Power Supply Cooling Fan	11	2.30%	~0.3%	High	High	3
Cable disconnected/ broken	9	1.88%	-	Medium	Low	4
Addressing of tile	7	1.46%	<<0.1%	Low	Low	2
Water Damage	5	1.04%	<<0.1%	Medium	Low	4
Power Surge	4	0.84%	~28.6%*	Medium	Low	4
Total	479	100%	-	-	-	-

* Seemingly high relative occurrence rates, however, these failures occur per screen, which means that it is actually a very infrequent in absolute numbers.

Table I above shows the absolute and relative occurrence numbers of different kinds of failure modes of the LED screens between September 2014 and April 2018. Note however that the total number of occurrences is higher than the number of instances in the database, this is due to the fact that in 1 repair, multiple failures can be detected and repaired. The number of undetermined repairs is unfortunately relatively high due to unclear descriptions of the maintenance or repair that has been executed. An often occurring failure is the “Tile defect”, according to Jan Löbker, this is caused by water damage in ±90% of the cases. This failure means one of the tiles needs to be replaced. The column that indicates “relative occurrence” is calculated by dividing the absolute number of failures of a certain part by the absolute number of units of that part that are present in the fourteen screens. For example there are 14 screens x ~100 panels per screen x 3 power supplies per panel ≈ 4200 power supplies. Of which 127 power supplies ≈ 3.0%.

Looking at severity, occurrence and whether a certain failure is detectable and predictable, possible starting points for a prognostics and health management systems can be identified. A failure mode that scores high on all four points is the power supply, also in conversations with employees of Hecla Professional BV, the power supplies came up as a main issue in the LED screens. All other modes have a much lower occurrence rate or cannot be attributed to a specific failure mechanism. This has lead to the main focus of this graduation project to be the power supplies in the LED screen.

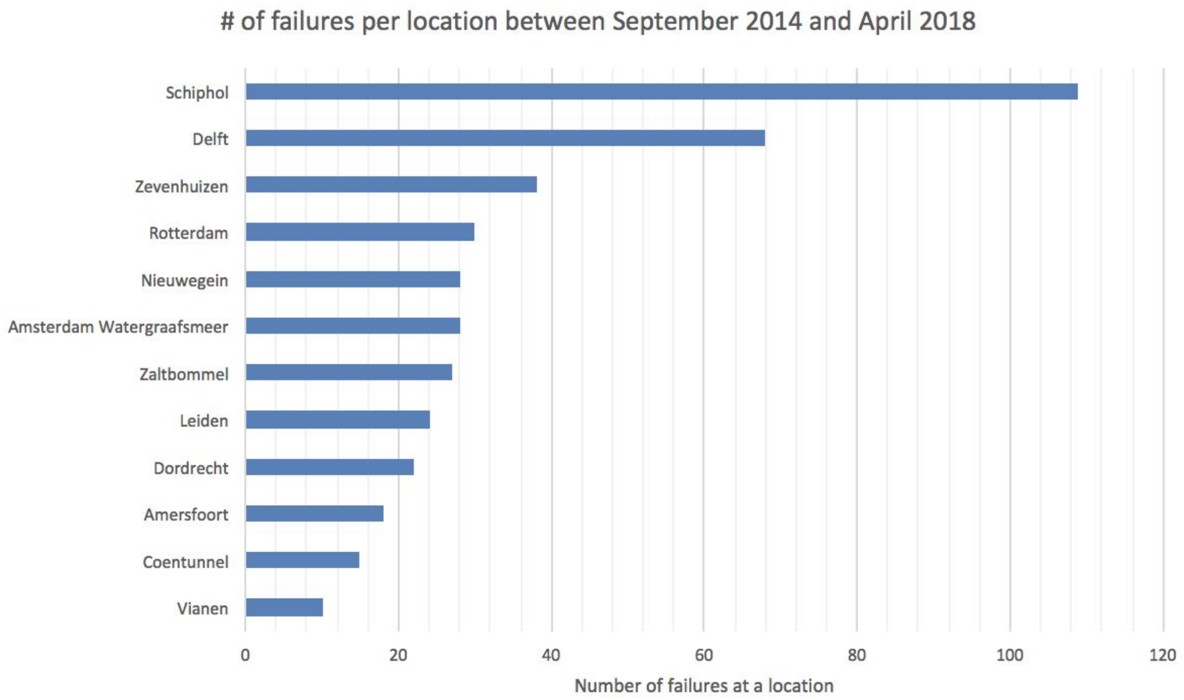

Fig. 5: Number of failures per location between September 2014 and April 2018

In figure 5 above, the number of failures per location is plotted. Clearly visible here is that Schiphol and Delft are outliers, which can be confirmed using the SPSS statistics package [8], that calculates outliers using the 1.5 x IQR method. For Delft this mostly is caused by a different kind of installation than in the other screens, the screen in Delft has been placed slightly hanging forwards. According to the manufacturer this should not have been a problem, but enabled a lot of water to run into the screen causing the screens to malfunction because of the water. The screens are not all placed at the same height, this could also have an influence on for example vibrations in the screen or other environmental variables. One parameter that is definitely the same for all screens is that the screens are only turned on during the day and are in standby mode during the night.

The screen at Schiphol is the screen with the highest number of malfunctions, namely 109 over the period from October 2014 until April 2018, which is almost 11 times higher than in the screen in Vianen and almost 4 times higher than the average. The employees at Hecla have investigated this, first by themselves, later also with the manufacturer of the panels, but no apparent reason for the high number of failures could be found.

The undetermined class of failures seems to be unevenly large compared to others, however as this is undetermined, there is not a lot that can be said about it. ‘Undetermined’ means that from the maintenance logs it was not apparent what kind of failure mode was detected or what kind of maintenance had been performed. In figure 6 below, next to Zevenhuizen, Dordrecht seems to be the only location plagued by cabling issues and Vianen seems to have a relatively high NPC failure rate, however, Vianen has the lowest failure rate in general. Therefore this means that in absolute numbers Vianen does not have unreasonably many NPC failures. In general it can be concluded that there are no locations with significantly uneven distributions of the failure modes.

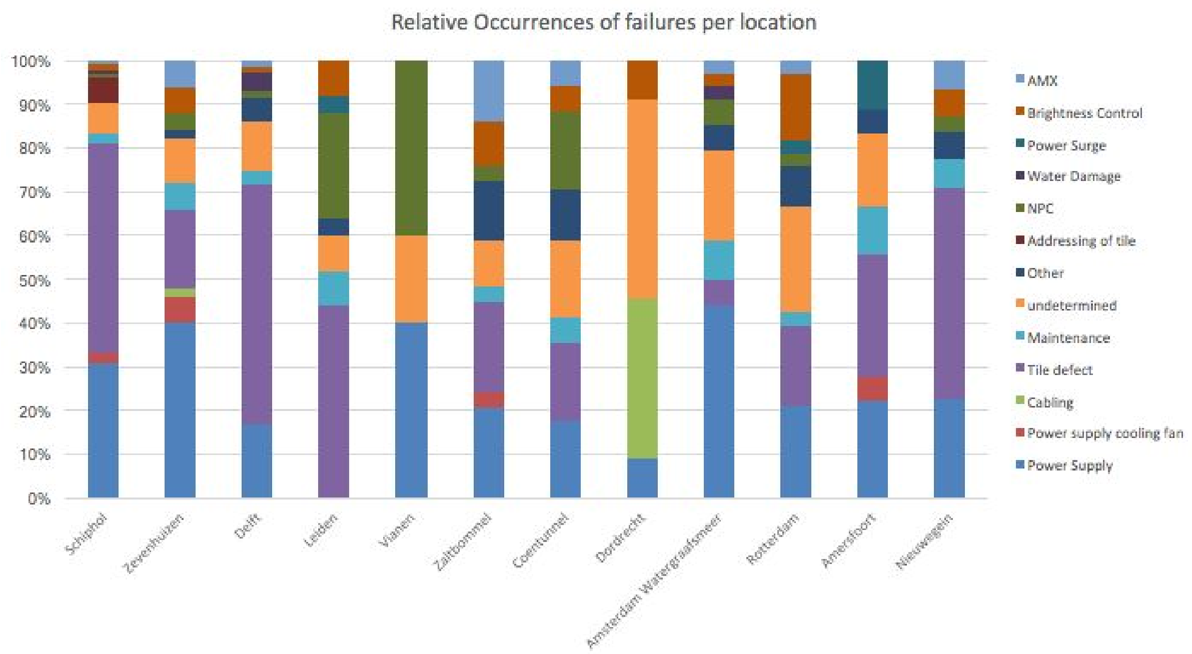

Fig. 6: stacked bar graph of relative occurrences of LED screen failures per location

6. Power supply

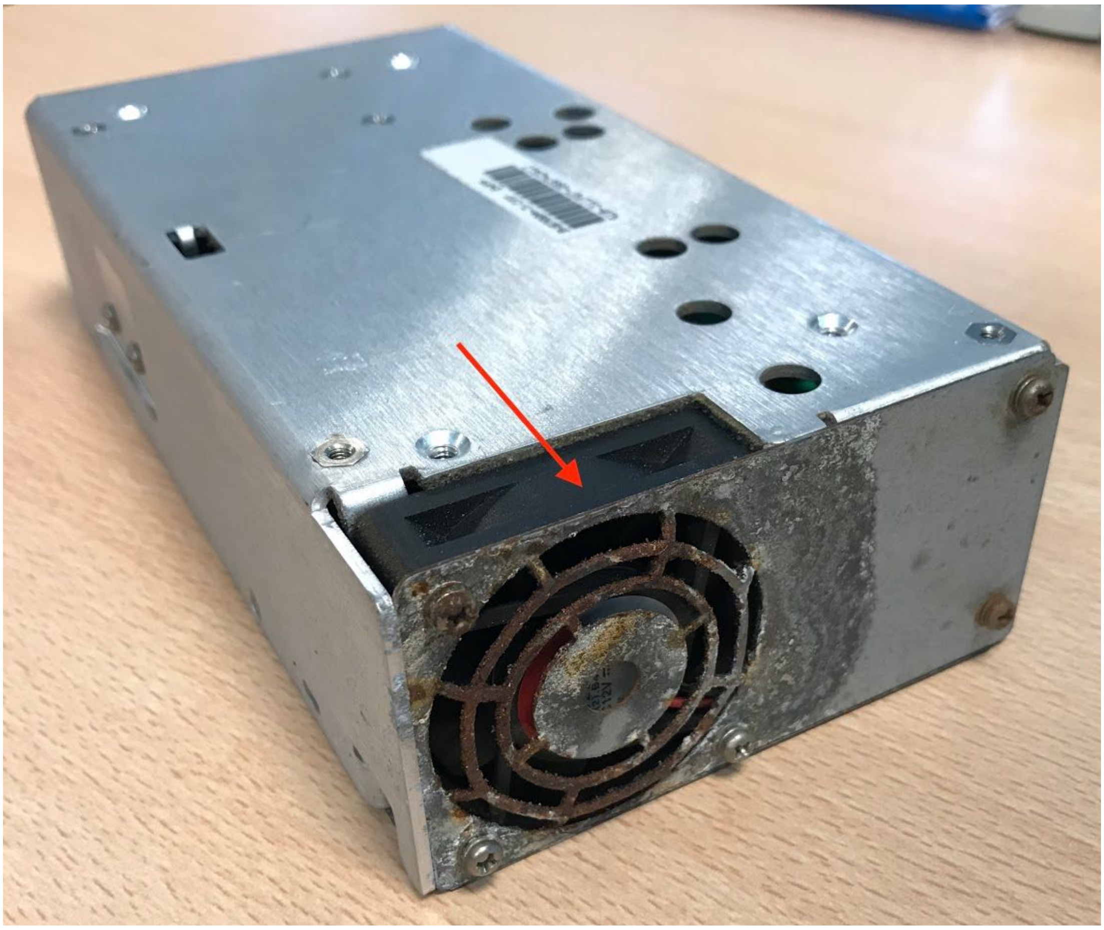

Fig. 7: Corroded power supply, TDK-Lambda sws300A-3/c02

In the Screens, 4 different kinds of power supply are used, of which two types are meant for powering the actual LED's. The other two types will not be discussed as they have no particular issues. The power supplies used in the LED panels are the TDK-Lambda sws300A-3/c02 and TDK-Lambda sws300A-5/c02, both 300W and 3.3V respectively 5V power supplies [9]. These are virtually the same power supplies, the only difference is as mentioned, the output voltage. The housing, cooling mechanism and other internals are virtually identical and so are the failure modes and mechanisms. In Figure 7 one of the corroded power supplies is shown, it is clearly visible that mainly the vent mesh behind the fan is subject to corrosion. The flow direction of the fan is indicated on the photo by the red arrow. Employees at Hecla argue that this corrosion is the cause for the power supply failure. From experience they know that often this cooling fan fails, causing the power supply to overheat and go into thermal shutdown. In their experience, there are more power supply failures during summer and/or hot periods than during winter/cold periods. More information about this interview with Hecla employees can be found in Appendix A. Mingzhu, Zhang, Zebing et al. identify high ambient temperature and high humidity as one of the main causes of power supply failure [10]. Zhou, Li, Ye et al. [11] have shown that temperature is an important degradation factor in LED drivers, which are comparable to SMPS power supplies. Jin, Azarian, Lau et al. [12] classify motor corrosion as a high risk failure mechanism in cooling fans, often caused by high humidity and high temperature. Another failure mode found in the FMMEA by [12] is seizure, which can be amongst others caused by entry of water and debris.

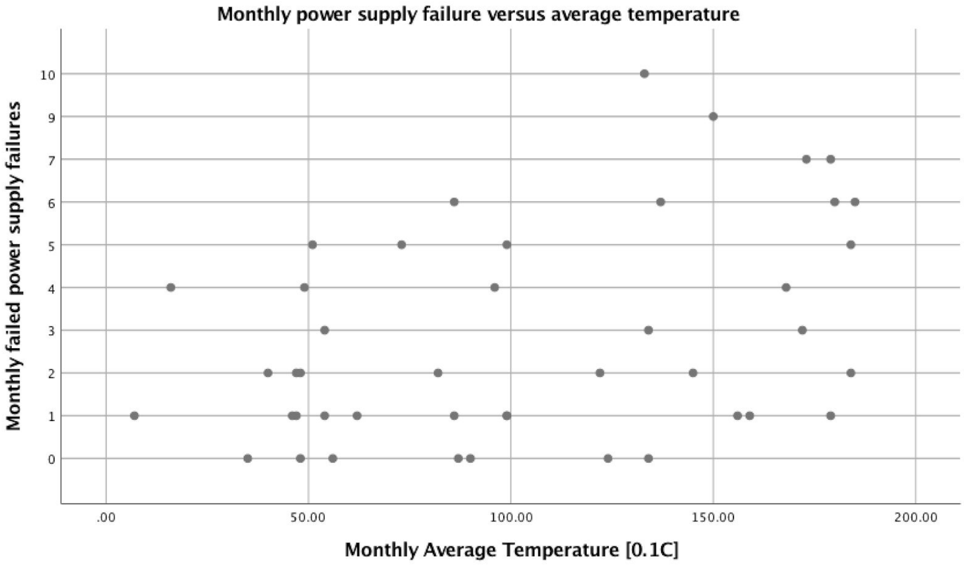

Fig. 8: Monthly power supply failure versus average temperature

As the Hecla employees are quite certain that there is a link between outside temperature and the failure of the power supplies, analysis of the failure data together with weather data has been performed. Many different combinations have been tried, either with the daily, weekly or monthly number of failed power supplies. In general the highest correlations were achieved with the monthly figures, this could indicate that the influence of temperature is an accumulative process that accumulates stress over a period of time before failing ‘catastrophically’ or noticeably. These daily/weekly/monthly failure figures were correlated with a number of different variables, including:

- Maximum daily/weekly/monthly temperature
- Minimum daily/weekly/monthly temperature
- Average daily/weekly/monthly temperature
- Average daily/weekly/monthly humidity

- Maximum daily/weekly/monthly humidity
- Number of daily/weekly/monthly hours with sunshine
- Solar radiation intensity
- Distance from the sea

In Figure 8 we see a scatter plot of the number of power supply failures per month plotted versus the average temperature in that month. Temperature data from the Royal Netherlands Meteorological Institute [13] was used. The graph displays a relatively weak but not insignificant correlation, where a higher average temperature correlates to a higher number of failures. SPSS statistics [8] assigns a correlation strength value of r=0.384 to this dataset and indicates that the correlation is significant at the 0.05 level with n=44. This is an important finding as it confirms what Hecla employees indicated about the frequency of power supply failure in these LED screens. We can see that the frequency almost doubles in months where the average temperature is higher than 14 degrees celsius, this can be seen even better in figure 9.

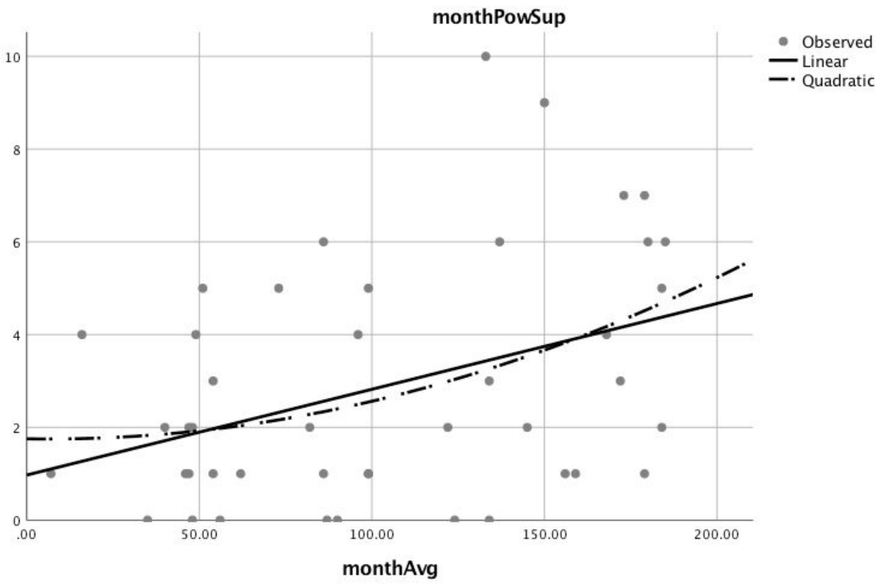

Fig. 9: SPSS curve fitting of the monthly average temperature [0.1℃] versus the number of failed power supplies

The best curve fitting in SPSS [8] (figure 9) is achieved with a quadratic curve, achieving an R^2 value of 0.155, however this is not far from the score of the linear curve which achieves an R^2 value of 0.148. Both are far from ideal and are not accurate enough to be used for prediction, but it does show that there is an average increase of 2 failing power supplies per month extra with an increase of about 10 degrees Celsius. In [14] the Arrhenius

Equation is used to model the degradation curve of a power supply under different temperature conditions. It would be possible to also use this to model the degradation behaviour of the power supplies if information about how long a certain power supply has been in operation had been gathered as well. What is possible to conclude from the above graph is the Arrhenius Q_{10} value, this indicates the strength of the temperature dependence. This can be calculated with the following equation:

$$Q_{10} = \frac{R_2}{R_1}^{\left(\frac{10}{T_2 - T_1}\right)} \quad \text{(Equation 1)}$$

Where R_2 and R_1 are the rates at temperature T_2 and T_1 respectively. Calculated with the following values, (57, 2) and (161, 4) the value for Q_{10} equals 1.947. Q_{10} Values for chemical processes like degradation, in this case corrosion are usually around 2-3.

Another correlation factor has been analysed namely the distance of a screen to the North Sea. This could be relevant as the main failure mode is corrosion, closer to the North Sea, the air conditions will likely be less fortunate for the LED screens. In Figure 10 below we see a scatter plot with a linear regression of the trend in the data. This data shows a correlation value of -0.339 which is negative because the higher the distance the lower the amount of failures. The linear approximation receives an R-Square score of 0.115. Both the correlation and R-square values are quite low, which indicate that the correlation is probably insignificant. A correlation like this one can of course be completely coincidental and as there are little data points available, the significance of the current data is low.

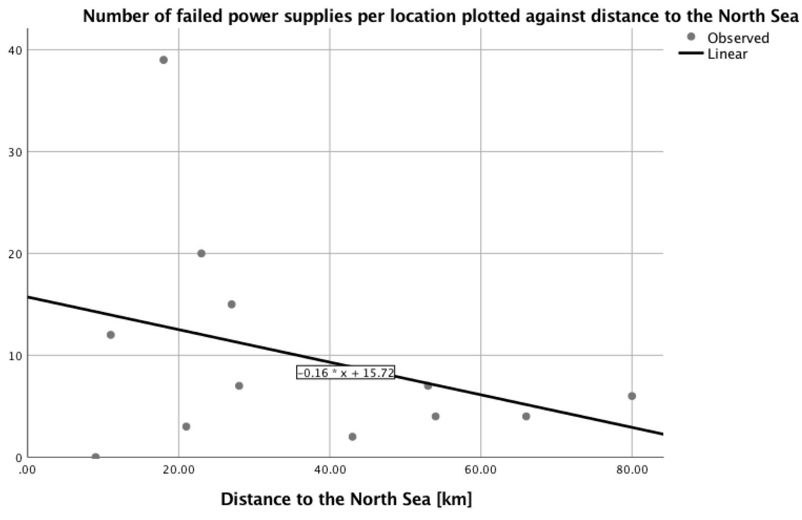

Fig. 10: Number of failed power supplies per location plotted against the distance of that location to the North Sea.

Another variable that could possibly have a significant impact on failure occurrence is the amount of sunlight that the screen is exposed to, indirectly the direction that the screen is pointed at. Some screens are in direct sunlight during most of the day whereas some screens are barely in direct sunlight at all. In figure 11 below, the angle of the direction of the screen relative to the north is plotted against the number of failures in the screen.

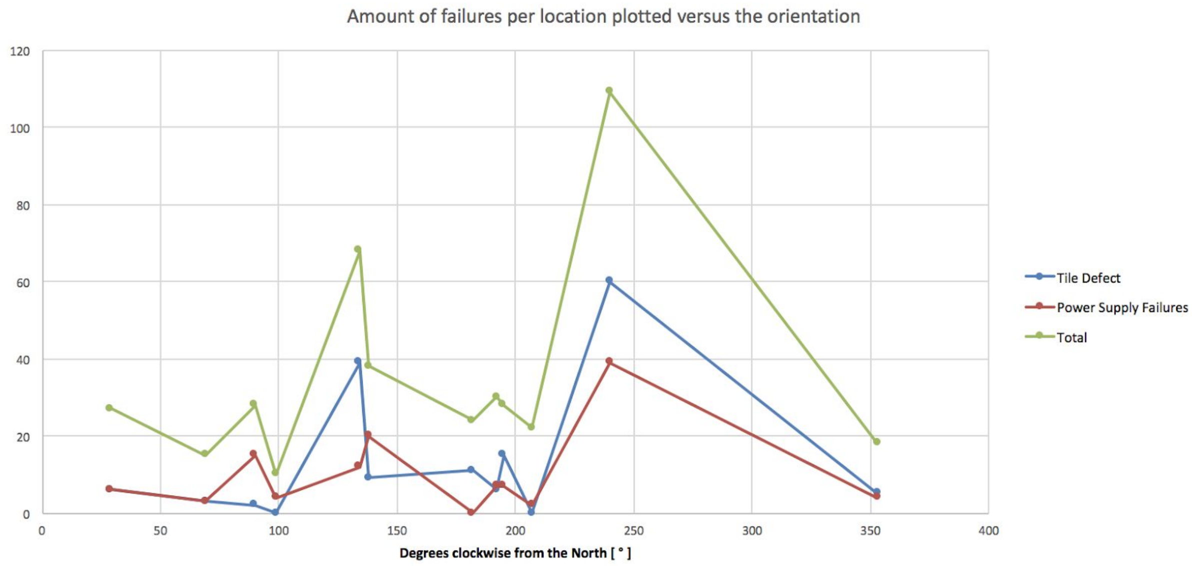

Fig. 11: amount of failures per screen plotted against cardinal direction

It is clearly visible however that this dataset is mainly completely random and does not show any sign of a possible correlation. Because of this, no statistical analysis has been performed on the data.

7. Failure Modes, Mechanisms and Effects Analysis of Power Supplies

As mentioned in the State of the Art research, Failure Modes, Mechanisms and Effects Analysis is an integral part of the preparations towards the implementation of a PHM system. Therefore this section will focus on performing this analysis in order to determine an approach for the next steps.

Failure of a power supply can occur because of different reasons. Power supplies are used in almost every electrical product, a lot of research has already been done as to why and how power supplies fail. In addition to the information from Hecla employees, a few more failure mechanisms exist. In Table II an FMMEA overview is given of the most common failure modes and compared with the failure modes observed in the LED screens. Cooling fan failure can be found in literature as a standalone issue, but is almost never mentioned as a main failure mode of power supplies. The table below is composed of information from different literature sources and information from Hecla, wherever a literature source is used it is referenced in the table itself.. The information about the Cooling fan failure has been retrieved from interviews with Hecla employees of which transcriptions can be found in appendices A and B.

From conversations with a Hecla employee it appears that in the current situation, there are no other significant failure modes known for the power supplies. This is likely because of the relatively very high cooling fan failure, causing the other failure modes to disappear as their occurrences are relatively low. A risk in this situation comes up when the cooling fan failure is adequately prevented, making other failure modes relatively more prevalent. This new failure mode will however have a much lower occurrence than the current main failure mode. These numbers are however based on estimates of employees of Hecla, as there is no documentation of the exact number of failures with a certain failure mode.

The datasheet of the power supplies [9] does not mention whether the power supply is based on MOS or bipolar transistors. In this section the power supplies are assumed to be based on MOSFET technology.

From this analysis it becomes clear that there is a significant mismatch between occurrence of certain failure modes in literature and these failure modes in the power supplies at hand. This could be explained by a design flaw of the power supplies, flawed installation, use of the equipment beyond its specifications or that the literature was not representative for the situation or this specific power supply. The latter of which is fairly improbable as the power supply is a somewhat generic switched-mode power supply of a well known brand, with literature that is mostly focused on switched mode power supplies as well.

Table II: FMMEA of the power supply

Failure site	Failure mode	Failure mechanism	Effects	Occurrence [15]	Occurrence at Hecla
Cooling Fan	Thermal Shut-down	Humidity→ corrosion → no power to fan	Thermal shut-down → no power to part of LED's: part of screen gives wrong colours	Unknown from literature	±99%*
MOSFET	TDDB (Time Dependent Dielectric Breakdown)	Conductive path forming Decrease in transconductance, Increased threshold voltage [16]	Power supply malfunction - Decreased output voltage - No output	31%	<1%*
	Activation of Parasitic Structures		Change in V_{DS} Change in output voltage [4]		
Schottky Diodes	Catastrophic failure	Die cracking	Diode short circuit → causing MOSFET/IGBT failure[17]	3%	<1%*
	Non catastrophic failure	Degradation: increased on-resistance	Increased reverse leakage current [15]		
Capacitor	Catastrophic failure [18]	Short circuit of capacitor	Decreased output stability (increased ringing & ripple) [16]	60%	<1%*
	Non catastrophic failure [18]	Increased Equivalent Series Resistance, decreased capacitance			

* Estimations based on information from Hecla employees

8. Ideation

To get an overview of the different possibilities an ideation phase was included and in order to find these different data acquisition solutions for the PHM system, a brainstorm was done. In figure 12 a mind map of this brainstorm is presented and multiple different solutions have appeared, all with their respective advantages and disadvantages. In this section these solutions will be discussed one by one, elaborating on their relevance, usefulness and ease of implementation. Possible constraints and restrictions of each data acquisition method are mentioned where present, to aid in finding the best option(s).

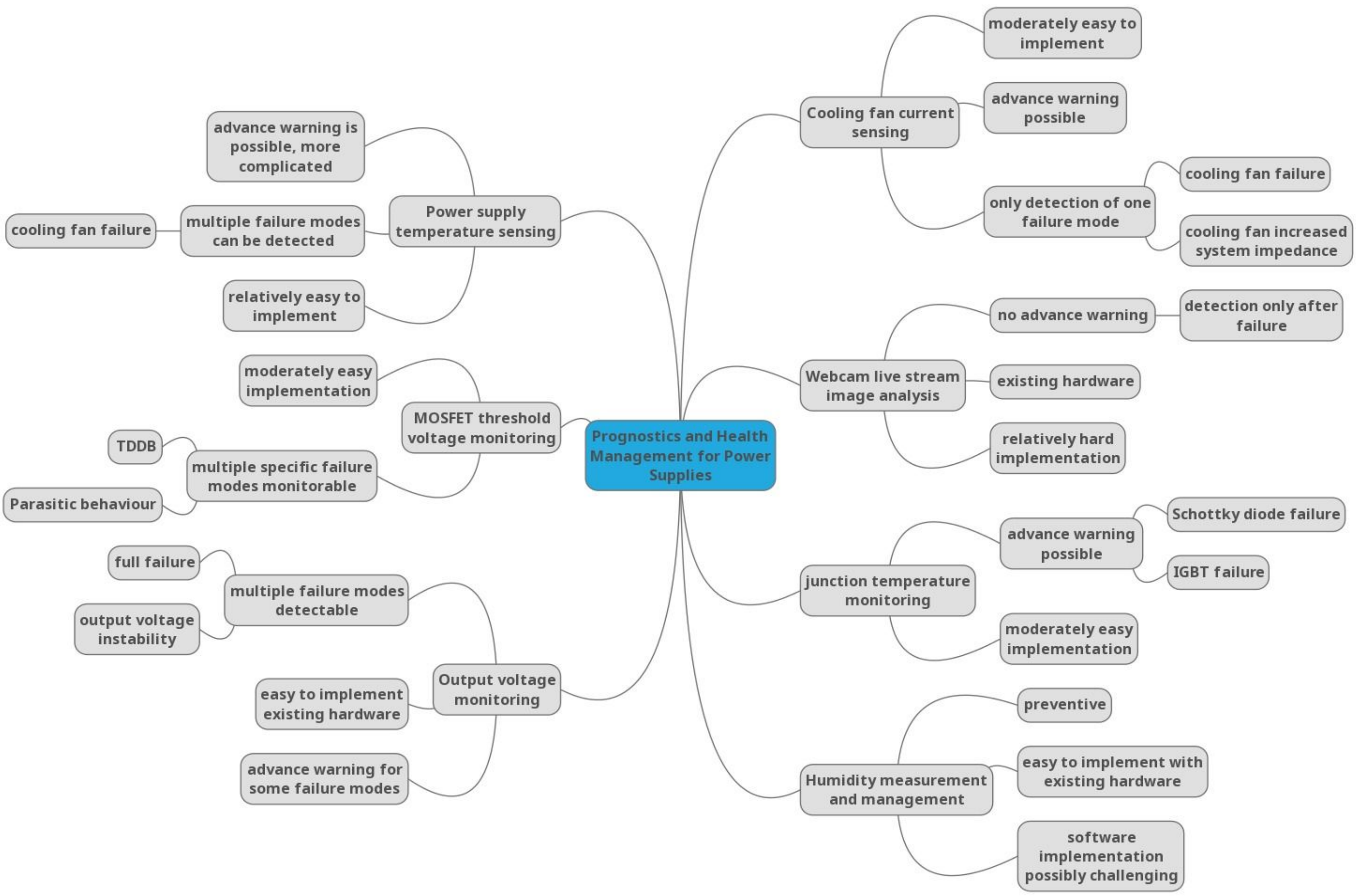

Fig. 12: mind map of possibilities for PHM of the LED screen power supplies and the implications of the proposed solutions.

Cooling fan current sensing

As discussed in previous sections, cooling fan failure accounts for a significantly large portion of power supply failures at Hecla. By implementing current sensing of the cooling fan, the state of the fan can be monitored and imminent failure of the fan can be detected. Wen and You [19] indicate that current can be used as a precursor parameter for identifying whether the fan is blocked, is failing or that the performance is degrading. This in turn indicates power supply failure as the cooling fan failure is the cause of the power supply failure. Advance warning in this option is therefore one of the advantages of this implementation, the implementation itself however is harder than with other options. There is no current sensor present in the panels as is, so implementation is more complex. Another downside of this option is the fact that it is only useful for detecting one failure mode, this is however the most prevalent failure mode.

Webcam Live Stream Image Analysis

The main advantage of this option is that it can be implemented without the need for new hardware at the LED screen. Which is also the only advantage, because apart from that the implementation is quite complicated. The content on the screen changes constantly, which means that it is hard to establish a baseline for image analysis. Another disadvantage is that it cannot easily predict failure, as it can only detect malfunction that is visible on the screen. It can however detect any failure that is visible on the screen, thus it is not limited to one failure mode. With very sensitive cameras the exact colour of the LED’s could be measured, when LED’s age their colour starts to shift towards a more red/yellow spectrum, which can be used to predict LED failure. This failure mode is however relatively infrequent and the implementation of such a system very complex.

Junction Temperature Monitoring

Junction temperature monitoring is a method that enables the user to gain information about the state of Schottky diodes and/or Insulated Gate Bipolar Transistors (IGBTs). An elevated Junction temperature in Schottky diodes can indicate catastrophic failure or Hot Carrier Injection in IGBTs [4]. Advance warnings of these failure modes is possible as the increase of this parameter happens gradually. The implementation of this method is again quite complicated however, as extra and most of all relatively intrusive hardware is needed to measure the voltage that the junction temperature is derived from.

Humidity Measurement and Management

A promising implementation more in the direction of Health Management, could be Humidity management. As the corrosion in the power supply is mainly caused by a relatively high humidity in cold weather. Proper management of these circumstances could help to prevent this corrosion. Because temperature measurement is already implemented and humidity measurement should according to one of the Hecla employees be implementable using the existing hardware in combination with directly compatible hardware, this method is one of the more easily implementable options. As can be read in Appendix B, this solution has been tested and unfortunately failed in a trial by Hecla, due to highly decreased stability of the system.

Power Supply Temperature Monitoring

With no additional hardware needed, this is probably the method that's most easily implementable, there is however only one temperature sensor per LED panel. Each LED panel contains 3 of the power supplies that are affected by the fan issues, which can thus not be monitored separately. The downside of temperature monitoring is that the temperature inside the panels is highly affected by sunshine causing the temperature to increase. This could cause the system to give a lot of false positives. Next to this, the temperature of the power supplies will only start rising after the cooling fan has failed or when the cooling fan is malfunctioning. This means that there is little time in advance before failure. Another risk is that the temperature rise of the power supply/supplies only has a very small effect on the temperature in the cabinet, causing the changes not to be measurable.

MOSFET Threshold Voltage Monitoring

MOSFET threshold voltage monitoring is a parameter that can indicate failure due to time dependent dielectric breakdown or activation of parasitic structures in the MOSFETs. These are according to literature [4][15] failures with relatively high occurrence rates. Combining these measurements with well calibrated decision algorithms, this method can give advance warning of imminent failure. In the case of the Hecla power supplies however, these are very low occurrence failures compared to cooling fan failure. This in combination with a relatively complex measurement and implementation process, makes this option not very attractive.

Output Voltage Monitoring

Output voltage monitoring is a parameter that can easily be used to indicate different failure modes. Measurement of the output voltages of the power supplies is already built-in in all LED panels of the Hecla screens. Output voltage is a very good indicator for output capacitor degradation, as the amount of ripple on the output is a direct measure for the state of the capacitor [16]. Next to that, output voltage can of course also be used to detect full failure of the power supply, however advance warning in case of full failure is much harder.

A Combination of the Above

None of the single solutions above is perfect and none of them are able to indicate all failure modes. A combination of multiple solutions however can come a long way in detecting different failure modes with a higher accuracy than a single method can. In general the solutions with easy implementation have reasonable usefulness and because they are easily implementable it is not much extra work to implement them in combination with another method. The choice for one of the other methods should be made consciously as not all of them are very useful. More elaborate research should be done to assess which measurement methods are useful as it is unclear which failure modes actually occur often in these power supplies next to the cooling fan failure.

Current trials

Hecla is now also trying something different, this winter for the first time, all panel fans were turned off. The idea behind this is that in winter the ambient temperature is low enough to cool the power supplies, while the heat from the different components will keep the panel dry on the inside. So far they have observed a decreased number of failed power supplies, but exact numbers are not available (see Appendix B).

A possible drawback with this solution is that during winter the temperature can become higher than desired, meaning that all components are exposed to a higher degradation factor. This could in turn lead to accelerated degradation of power electronics, microcontrollers but also the LED's, triggering other failure modes than before.

Drawbacks of the current hardware

The communication for retrieving the information from a panel, like the power supply output voltage is done via the same communication channel as the distribution of the video signals. The bandwidth of this channel is mostly occupied by the video signals, leaving little bandwidth for retrieving for example output voltages of some tens to hundreds of power supplies. This causes the update rate of this information to be very low, which means that in the case of voltages it is impossible to measure ripple levels in the output voltage as this would cause the screen to crash. The same goes for actively monitoring the temperature and humidity and adapting the ventilation speed to those values.

A possible solution for that is adding new hardware to each panel, a small microcontroller, temperature and humidity sensors, a small relay. If prognostics should be added, these also need a connection to the internet, making it even more complicated. Say one unit could be manufactured for around 5 Euro, equipping a screen of around 100m^2 with it would cost 640 euro in materials. The benefit of not having to replace as many power supplies for example should compensate for the cost of the system. Although this is a relatively more expensive solution, it might still be relevant, it will therefore still be taken into account.

9. Specification

Developing a system like this doesn't go without setting specifications for the desired end product. What features and properties should the system have to be useful and what should it not have? The title of this thesis reads: "Design of Data Acquisition Solution for Prognostics & Health Management in LED Screens". From the title, the main requirements can be deduced. Namely, Prognostics & Health Management, the system should be able to perform prognostics and health management on the LED screens. Prognostics and Health Management in this case referring to predicting and where possible preventing failure or improving lifetime. The system must in the first place be able to give advance warning of failure, with a reasonable prognostics delay, preferably in the range of 6 to 24 hours. This system must naturally have low false positive and false negative rates in its prediction. Next to that, the system must of course be remotely accessible, such that repair engineers can schedule maintenance in advance.

Although not within the scope of this research, cost efficiency is an important aspect of such a system. Within the scope of the research this implies that the system should be relatively easily implementable into the current hardware. The ability to predict and detect more than one failure mode is a secondary requirement, not the most important, but nonetheless desirable. The system will however not be made to be able to predict, detect or prevent all failure modes as this is practically impossible.

Table III: MoSCoW representation of the requirements

Must	Should	Could	Won't
- Advance warning of failure - Low number of false positives/ false negatives - Remotely accessible - No interference with content display	- Easily implementable in current hardware - More than one Failure Mode detectable	- Expandable	- Cover all failure modes

10. Realisation I: Short Term Improvements

The question from Hecla was if it was possible to make something to replace their current system for finding failures with a system that can find and predict when LED screens are or will be malfunctioning. The goal was in principle to analyse this and be able to produce a prototype or proof of concept. However, as has been established in the previous parts of this report, this is unfortunately not possible in the current situation. In the following parts of this report, an elaborate analysis of what would be needed for such a system will be presented. This will go into the need for more extensive documentation of maintenance and life cycles of the equipment, possible adaptations of the current hardware and possible additions to the current hardware. Instead of doing prognostics on the hardware, it would also be possible to implement a solution more directed towards Health Management. This eliminates the need for an extensive model of the failure mechanism, for example the regulation of fan speed with respect to temperature and humidity in the panel.

The goal now is to close with an analysis of the current system, what the constraints are, what is needed to implement prognostics and what other options there are to implement prognostics outside of the current hardware. Most of the analysis of the current system has been discussed earlier on in this report. A second realisation section has been added to this report to discuss a possible hardware design for a preliminary solution with added hardware.

Equipment Documentation

In preparation towards developing a PHM system, extensive information about the hardware is needed. As can be seen in figure 2, Physics of Failure models need to be established and existing sensor data needs to be present to be able to perform prognostics and health management. In the current situation there is no useable sensor data and no accurate data about what failure mechanisms occur in the power supplies. This prevents the necessary models from being established and makes it impossible to identify precursors to failure. One aspect that definitely needs to be improved is that data from the panels should be logged, establishing a database of precedent out of which precursors can be identified. On the other hand documentation should be constructed that keeps track of how long a certain part has been in place before it failed, what the failure mode was, whether it has been repaired or not, etc.

Current Hardware

An extra reason why implementation of a solution is currently not feasible is that the means of communication in the current hardware is insufficient to accommodate the extra traffic needed for PHM. Therefore an important next step is either improving the possibilities for connected hardware within the current hardware, or implementing new hardware. The latter will be discussed in the next section.

Improving on, or adapting the current hardware is a costly process, which will improve the stability of the screens in the sense that when implementing new software features, the screen will have plenty bandwidth left for its normal operation. The question is whether this is possible with the current hardware and/or if its desirable to retrofit the current screens instead of investing in development of a possible next generation.

Additional hardware for PHM

A potentially less radical possibility is to preserve the current hardware and add a piece of hardware that is specifically for the purpose of prognostics. However, in this stage there is no use for prognostics hardware as there are no identified precursors or established thresholds. To find these parameters, a field test would be necessary with a reasonable amount of test setups and a more detailed documentation of the failure. The data retrieved with this field test can then be used to find precursors, and establish baselines and threshold values.

In the case of added hardware, depending on what exact functionality is desired, implementing it will be a relatively big effort. Per panel hardware needs to be installed, connected to the components that need to be measured and if necessary connected to the internet in some way. In the following chapter, two possible hardware designs will be presented, one that focuses on health management for the temperature/humidity inside the panel as has been tried before (appendix B), and a second that focuses on measuring relevant parameters for finding precursors and establishing baseline and threshold values.

Preliminary Conclusions

Before a well-functioning PHM system can be developed and implemented into the screens, a number of steps have to be taken by Hecla. 1) An elaborate documentation should be kept about the equipment that is in place. Registering what parts are where, how long they were in operation for, when they were replaced etc. 2) For the parts that need PHM, in this case the power supplies, multiple parameters have to be monitored for a while, in order to establish baselines and register what parameters show useful precursors for failure prediction. Then, depending on what is preferable, 3a or 3b can be chosen in the next step. 3a) The screens need to be upgraded in some way to accommodate for the increased traffic needed for PHM. Or, 3b) Separate hardware needs to be developed to monitor the relevant parameters and connect to a central hub to distribute a warning that failure is imminent.

With these steps taken, PHM can be reliably implemented, without interference to the content of the screen. Once in operation the system will help in maximising the uptime of the screen and can give insight in negative circumstances for the screens.

11. Realisation II: Hardware Implementation

As mentioned in the previous section, this section will propose two hardware designs in the run up to PHM. One of the designs directed more towards health management, the other towards finding precursors for failure in the LED screen. Both designs are meant to operate in a standalone fashion, not relying on communication protocols of the existing hardware.

Health management

The first design uses temperature and humidity measurement to regulate the air flow into the panel. The goal is to keep the humidity in the panel as low as possible such that corrosion is prevented and to maintain a low enough temperature inside the panel for the cooling of the electronics. This can be both implemented with a single board computer or a small microcontroller as there is no need for network communication. In figure 13 a schematic drawing for the implementation of such a system is presented. It uses a Raspberry Pi as a processor, connected to a simple temperature and humidity sensor. Using the values from these sensors a decision is made on whether the cooling fans that blow outside air into the panels should be turned on or off. An added functionality for this option could be to either measure the outside temperature and humidity and take this into account for the decision on the cooling fan. Or to retrieve this information from a website, using the networking capabilities of the Raspberry pi.

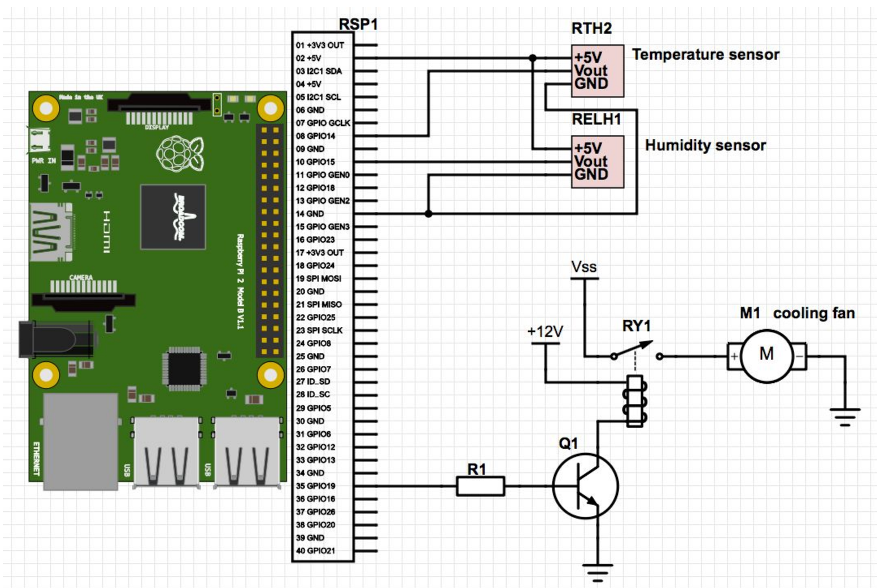

Fig. 13: schematic of possible temperature/humidity management for LED panels

Precursor parameter extraction

The second option is to implement hardware that is focused on finding and extracting precursors to failure in the parameters of the LED screen hardware. As mentioned before, parameters that are of interest to monitor include the following:

- Cooling fan current;
- Output voltage;
- MOSFET gate leakage current;
- MOSFET threshold voltage;
- Etc.

As much data as possible should be gathered, such that the precursor parameters can be reliably extracted and validated. Validation can be done if enough data has been gathered such that the failure has occurred multiple times and every time similar behaviour is observed. Measuring gate leakage current and the threshold voltage is quite invasive, whereas the cooling fan current and the output voltages can be measured relatively easily. With this system, a network connection is necessary as the measurement data has to be linked to the failure data. The failure data in this stage still has to be registered manually, after the data gathering stage this data can then be used to predict failure automatically. An example design of such a system can be seen in figure 14.

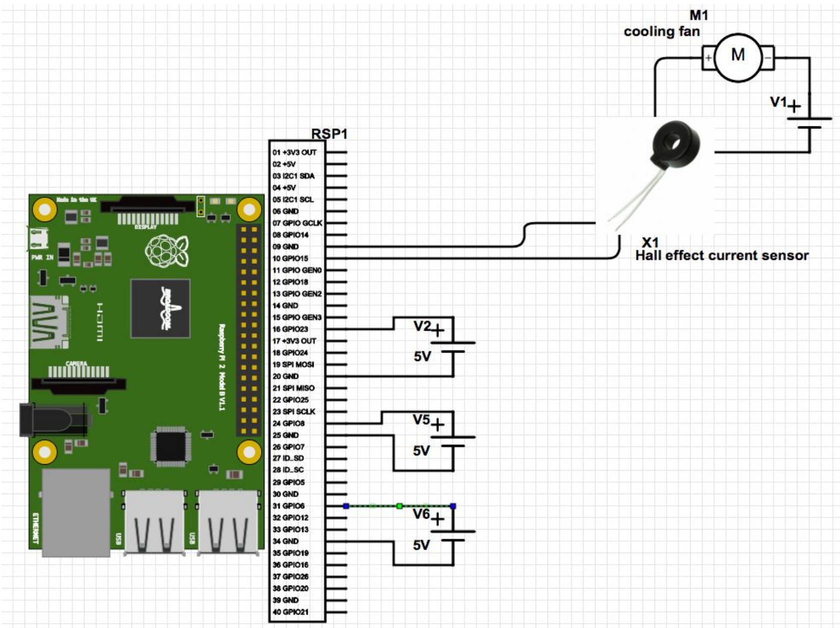

Fig. 14: schematic of possible precursor parameter extraction hardware

12. Conclusion

In the current situation, PHM can be of great help in predicting failure and therefore preventing downtime, but with the right implementation could even prevent failure in the first place. From the maintenance documentation it was possible to substantiate the need for PHM. With a failure rate of 3% in for example the power supplies or 0.5% in the LED tiles, PHM becomes a viable option as the number of failures has to be high enough to make PHM profitable. The need for PHM has thereby also been shown. However, the current maintenance documentation and in extension the current hardware prevent rapid and easy implementation of PHM. More information and data from the screens is needed to design a system that uses relevant parameters to predict failure. In chapter 10 a number of recommendations are given to prepare for a PHM system.

Included in chapter 10 is also some information about the communication architecture of the screen, according to the documentation of the screen, it is designed to also be used by diagnostics information like temperatures and supply voltages, however in practice Hecla found this to not be functional in a useful way. This also creates the need for improved hardware or stand-alone hardware.

The suspicion by the Hecla employees that there is a causal relationship between temperature and the amount of power supply failures has been partly confirmed by the correlation analysis performed in chapter 6.

Chapter 10 gives a fairly comprehensive answer to the main research question, namely that with the currently available sources of data, PHM is not yet possible, but that it would be possible after implementing more hardware for monitoring and logging. Next to that, keeping an extensive documentation of maintenance on the hardware is advised.

13. Future Work

This research already proposes quite a few directions for future investigation throughout the report, there are however more possibilities. This section will start by giving an overview of previously mentioned future work options, after which the other options will be discussed. The main product of this research was a set of recommendations to Hecla to enable PHM, these recommendations form the basis for further research or further action on this.

One of the main points of attention in working towards a PHM system for the LED screens is the acquisition of more data about (in this case) the power supplies. There are two ways to go about this. First, Hecla could start documenting their equipment, the use and replacement of it and lifespan of components more elaborately. Over time, this would create a large database of failures and enable a researcher to accurately establish a knowledge base on which the PHM system can be built. Second, Highly Accelerated Life Testing (HALT) and Highly Accelerated Stress Testing (HAST) could be performed on a number of power supplies [5]. This quickly solves the issue of lacking data, however this testing is usually destructive and means that quite some power supplies will be destroyed which costs quite some money. In this testing precursors to failure can easily be gathered, including gaining more data on how the power supply degrades under increased thermal (and oxidative) stress.

If the first option is chosen, for Hecla to start accurately documenting the replacement, maintenance and installation of material, research could focus on how to document this. Either in a way that optimizes the amount of data for PHM or in a way that optimizes the workflow for the people who have to enter the data into the system. Possibly integrating this functionality into the software that is currently used.

Once PHM has been implemented for the power supply, only one quarter of the failures will have been accounted for. Therefore after a while having worked with the power supply PHM system, it should be inventoried whether the prevalence of the different failure modes has changed. An assessment should be made whether PHM on different parts of the LED screens is necessary in addition to the (by then) existing system.

14. Reflection Report

My Graduation Project

Along different highways in the Netherlands, LED advertisement screens are placed, 14 screens in total. Every once in a while these screens break down, a component breaks down and has to be replaced. A service engineer has to go onsite to fix this issue. The service engineers know when a screen is broken by monitoring the screens through a system of webcams. Hecla, the company that has developed these screens, would like to introduce a system that automatically detects failure of a screen without the direct observation of a service engineer. Even better would be a system that recognizes the pattern of a component breaking down and being able to predict that a certain component is about to break down, minimizing the down-time of the screens.

These screens can be up to 110m^2 big, therefore hard not to see while driving down the highway. Which is good for the companies that are advertising on these screens, eye-catching advertisement screens increase their sales. Especially when the screens are digital, the advertisement costs little as there is no need for someone to go to a billboard to put up the advertisement. The non-financial cost however, might be higher than that. When the advertisements are placed along highways, drivers can easily be distracted by the contents shown on the screen. This report will look into whether drivers are significantly distracted by these screens, and the moral implications of this issue. If this is a significant hazard for drivers, just like second hand smoking was a serious hazard in pubs, regulations could be used to prevent it from happening. These issues and examples will be discussed in more detail in the following sections of the report.

Traffic Deaths Caused By External Distractions

The first question one should ask themself is whether the screens actually cause more accidents along the roads that they are placed next to. This will be discussed and analysed using research about traffic safety. In later chapters this will be compared with other issues like smoking in public areas.

If the advertisements actually cause more accidents, then why are they still there? Of course the people using the advertisements have an interest in keeping them there as they get increased profit from the screens. From the utilitarian viewpoint, one could say that the profits for the advertising companies are higher than the losses caused by accidents, thus the good compensates for the bad.

Amongst the various researches into traffic distraction, there are a lot of different conclusions. Some clearly link roadside advertisements to distraction, others are highly doubtful of a direct link between advertisements and traffic safety. The more recent research however tends to point towards a distinctive risk when it comes to distraction by roadside advertisements. This is however often situation dependent [20][21][22][23]. Specific situations with higher cognitive demand from the driver are for example curves and intersections, which leaves less cognitive capacity for other driving tasks and distractions. From the viewpoint of the LED screens, the brightness could be considered as another factor in this. The brightness of the screens is regulated automatically, to make sure that during the day, the content is clearly visible and that during the night, the screen isn't too bright. If this automatic control fails, drivers could be blinded by the screen, causing dangerous situations. The fact that placement of these screens contributes to the level of risk created, means that the people placing these screens have influence on the distraction level of drivers. A screen could be placed on a stretch of road with little other distractions, which helps the drivers to keep most of their attention on the driving task. For example, placing an advertisement in a bend is more attractive as it is in the line of sight of the driver, making it more likely that the driver is looking at it. The downside being that the driving task is more involved while (preparing to go through) going through a corner.

Relative to not placing an advertisement screen at all, trying to minimise impact on traffic is a fairly low threshold effort. When looking at this issue from the non-consequentialist point of view, the goal should be to inflict minimal or no harm to the drivers.

Government Regulations

The question arises, if this is indeed as the researches imply a traffic safety issue, shouldn't governments do something about it? Do governments already have legislation on this topic? On a national level, the dutch government decides whether advertisements along a highway are allowed as this is government property. On a regional level, the municipalities can decide what the regulations about roadside advertisement are along the roads in their municipality [24]. For both levels, permission has to be granted by the corresponding authorities. Next to direct advertisement, there are also regulations about placing advertisements in buildings close to roads, in/on cars parked next to roads, on private property next to roads etc. Advertisements not directly pointed at roads or smaller than $0.5m^2$ are exempt from these rules, important however is that advertisements which are illuminated or light emitting are always required to have a permit. This last rule has been added as a measure to prevent safety issues because of too brightly illuminated advertisements.

The Dutch SWOV, foundation for scientific research on traffic safety, has researched this issue, commissioned by the alliance of insurance companies [25]. This research is relatively dated, but nonetheless a relevant source of information. They start by stating that the amount of quantitative researches as to whether advertisements cause traffic incidents, is very meager. They do however conclude that advertisements do cause significant distractions in the “right” or better, wrong circumstances. Especially when the advertisement has a high contrast compared to the background, it is harder to refrain from paying attention to this. Even though according to the research, humans are quite competent at dividing their attention amongst the driving task and other distractions. Fundamental research has proven that it is especially hard to ignore illuminated, flashing or moving objects like advertisements on LED screens. This can cause information relevant for the driving task to be seen later or not to be seen at all. The committee concludes that with the traffic safety in mind, there should be regulations about to what extent advertisements can be distracting from the driving task. This kind of regulations already exist regionally but time and money should be spent on more elaborate research, with the goal to establish national legislation that is consistent with the findings from research.

How people deal with everyday risks

Driving a car is a risk, smoking cigarettes is a risk, taking an elevator is a risk, but how do people deal with these risks? In the previous section some literature was quoted which says that drivers are fairly good at making decisions on whether they have enough “mental capacity” to look at something non-driving related. Humans can usually estimate this quite well, ensuring that they cause no traffic incidents. Tannert, Elvers and Jandrig [26] describe a similar issue as follows. “A danger has a prescribed quality and a defined probability, and can therefore be avoided or counteracted. For example, car accidents that caused severe or deadly injuries prompted regulation for the mandatory installation and use of safety belts. By contrast, a risk can either be accepted by, or imposed on, a person. Driving without a safety belt is a self-accepted risk, while selling cars with faulty safety belts imposes a risk on unsuspecting buyers.” This raises the question whether the LED screen issue is a danger or a risk and if it is a risk, is it an accepted risk or an imposed risk?

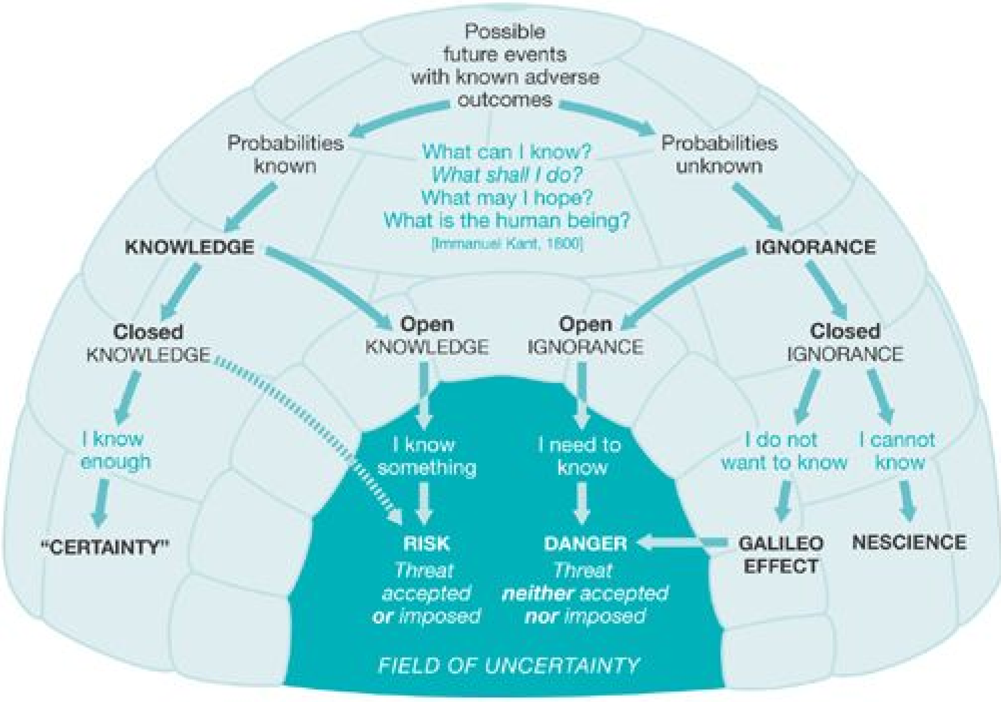

Fig. 15: The igloo of uncertainty [7]

In Figure 15 The igloo of uncertainty is illustrated, this figure helps distinguish between open and closed forms of ignorance and knowledge. In the case of the LED screens, one could argue that people generally have a sense of the probabilities, although not completely known, the probabilities are not unknown either. This corresponds with the "open knowledge" path of the igloo; "i know something". The igloo now tells us that the issue at hand is a risk and not a danger. But the more important question is, whether this risk is imposed on someone or that the risk is accepted by someone. To analyse this question, the next section will compare the LED screen issue with more generally known issues.

Alcohol, Tobacco and Phone Usage

In this section, the LED screens will be compared with three explicitly similar or distinctive cases, each with different aspects. These three cases are:

- Alcohol use while driving;
- Smoking in public places;
- Phone usage while driving

These cases will be compared on what kind of risk they form, whether they are imposed or accepted and how these are dealt with regulation/legislation wise.

Alcohol use while driving

Alcohol use while driving is comparable to the LED screens as it impairs the driver from paying adequate attention to the driving task and can increase the reaction time [20]. Drunk Driving is an accepted risk, the driver knows that the risk is there, but actively chooses to go through with it. When getting in a car, a driver also knows that there will probably be advertisements along the road that can distract them, however, the driver has not placed those advertisements there.

Legislation wise, strict national laws exist to prevent and punish drunk driving. It is however not the alcohol use that is punishable, but the act of being intoxicated while driving. The equivalent for advertisements could be not being allowed to drive on roads because there are advertisements along that road, which is not a viable alternative.

Smoking in public places

The adverse effects of smoking have been known since the mid 20th century, before that, to the users it was a danger. They had no knowledge of the adverse effects and were even made to believe that smoking was healthy. When it started to be clear that smoking was indeed very bad for people, it became ignorance. The tobacco industry created a Galileo effect as mentioned in Figure 15, where they refused to accept that this was the truth.

When more and more people started believing that smoking was actually dangerous, they started to quit smoking and it became risk acceptation for the people who did not stop smoking. Lately most developed countries have put in place laws to ban smoking from public places, like museums and bars/cafes. Before these laws, going to these places would be having a risk imposed on oneself. In a lot of places it was impossible to avoid being exposed to smoke, making this an imposed risk. Just like driving in a car, visiting public places is relatively unavoidable, which means that seeing advertisements is indirectly unavoidable as well. Legislation in most developed countries has now fortunately made it possible to avoid almost all exposure to smoke, which in turn means that this has now become a risk that is accepted and not imposed anymore.

Phone Usage while driving

Phone Usage while driving is probably the most similar to roadside advertisements, although this case also has a lot less precedent than alcohol and smoking. At the time of writing, phones by law cannot be used while operating a vehicle. This might change in the near future, thanks to self driving cars, but for now this is the situation. The reason that this is the case, is that phones especially smartphones are able to form such a great distraction, that this severely impairs the driver in performing the driving task. Phones draw the users attention by illuminating the screen, vibrating and making a sound whenever a message is received or when they are being called. Does that mean that phones are an imposed risk? Not necessarily, phones can easily be put away, put on silent mode, or even “driving” mode on some phones.

How does this relate to the LED screens? LED screens could be an imposed risk in the sense that they are there, virtually impossible to avoid. On the other hand, looking at the screens is not necessarily impossible, the screens are meant to draw attention with colour and animation but this can be ignored. One could thus argue that the screens are an accepted risk, looking at the screens is a risk that the driver accepts.

Legislation for phone usage while driving is quite strict in most countries. Usually it is only allowed to use a phone for calling while it is in a hands-free car kit. Extrapolating this to LED screens would mean that they would barely be allowed at all. However, a difference should be made between SLA’s (Street Level Advertisements) and RLA’s (Raised Level Advertisements). RLA’s like LED screens, are usually placed on a building or pole, higher than the road level. While SLA’s as the name says it are placed at street level like advertisement in bus shelters.

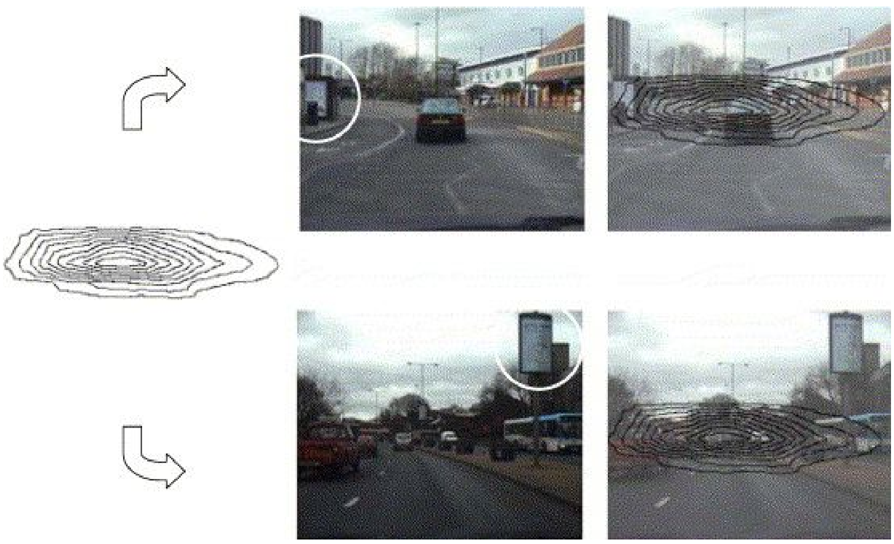

Fig. 16: Safety inspection window of an SLA versus an RLA [1]

In Figure 16 it can be seen that the RLA is far out of the focus area of the vision of the driver. This means that the RLA is easier to ignore than the SLA in the case where they draw equally much attention colour and animation wise.

Legislation or autonomy

Whether the LED screen issue is an accepted or an imposed risk, remains partly unclear. The similar issues are meant to create some insight into how these are handled, what kind of legislation is currently in place and if this is relatively similar to what was found for the LED screens. When looking at the phone usage while driving case, it is probably not useful to impose similar measures to that onto the drivers, as this takes away more of the autonomy of the driver. Legislation as it is now, is more directed towards the other party in this, namely the party that does the advertising. The strictness of the current legislation is noticeably lower than those of the mentioned examples.

Conclusion

Yes, LED screen advertisements next to highways and roads most likely cause accidents. However, more elaborate research needs to be done in order to establish how high the need for (improved) legislation is. The current legislation, at least in the Netherlands, seems to be adequate compared to the risk however, as seen in the comparison with similar cases the legislation is not that strict. For now LED screens will remain to be a reasonably safe means of advertising along a highway.

Appendices

Appendix A: Meeting with Hecla March 30th 2018

Leo Kuipers, Innovation Manager

Mike Bloemink, Sales Engineer

Jan Löbker, Sr. Operational Project Manager

Tom Quicken, Project Manager

The LED-screens of interest consist of the following parts:

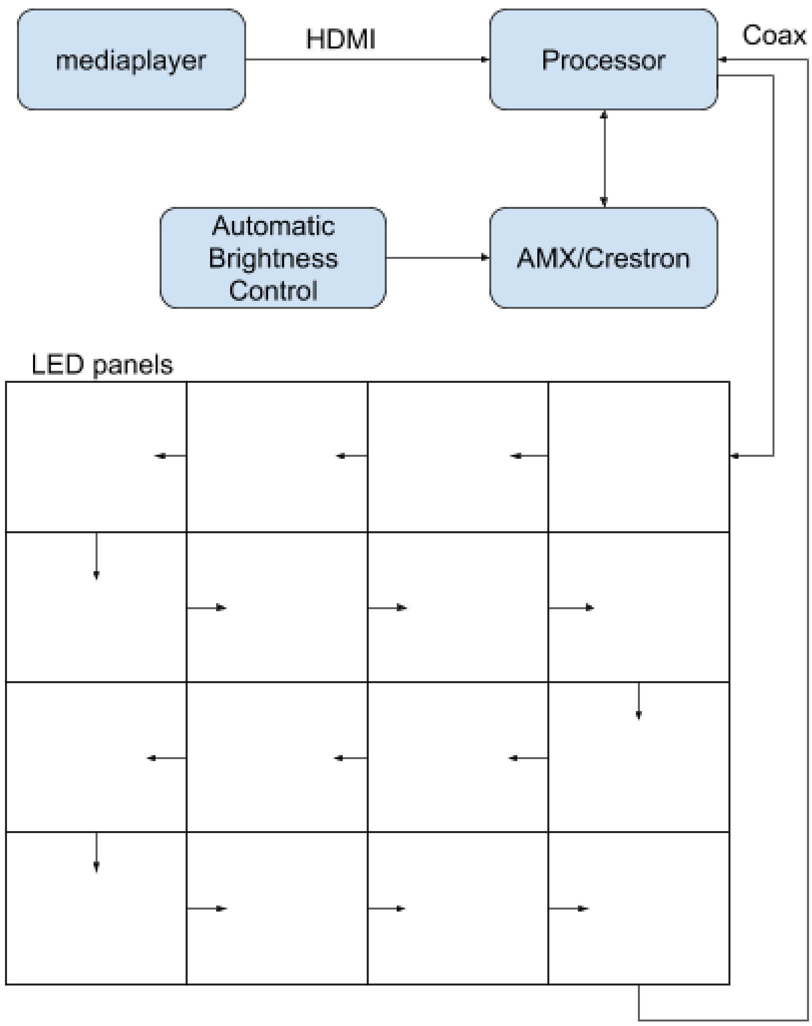

Fig. 1: schematic drawing of the electronics of an LED screen.

The content of the LED screens in sent through a normal HDMI input, which arrives at a processor, the processor translates this into a signal that is sent through a coax cable to the different panels. Next to the processor there is an AMX or Crestron, this part in combination with an LDR in the automatic brightness control, regulate the brightness of the screen making sure drivers on the highway aren't blinded by the screen. Each panel contains an NPC board, this splits the signal from the coax cable into 4x6 different parts and distributes them over the LED tiles. Connected to the NPC, the EMB is found, this controls the fan power and monitors the temperature in the panel. The screens of course need power, this is supplied by three power supply units in each panel. One power supply for red, one for green and blue of the left half of the panel and one for green and blue of the right half of the screen. The close up of one panel with all the internals described as above can be found in figure 2 below.

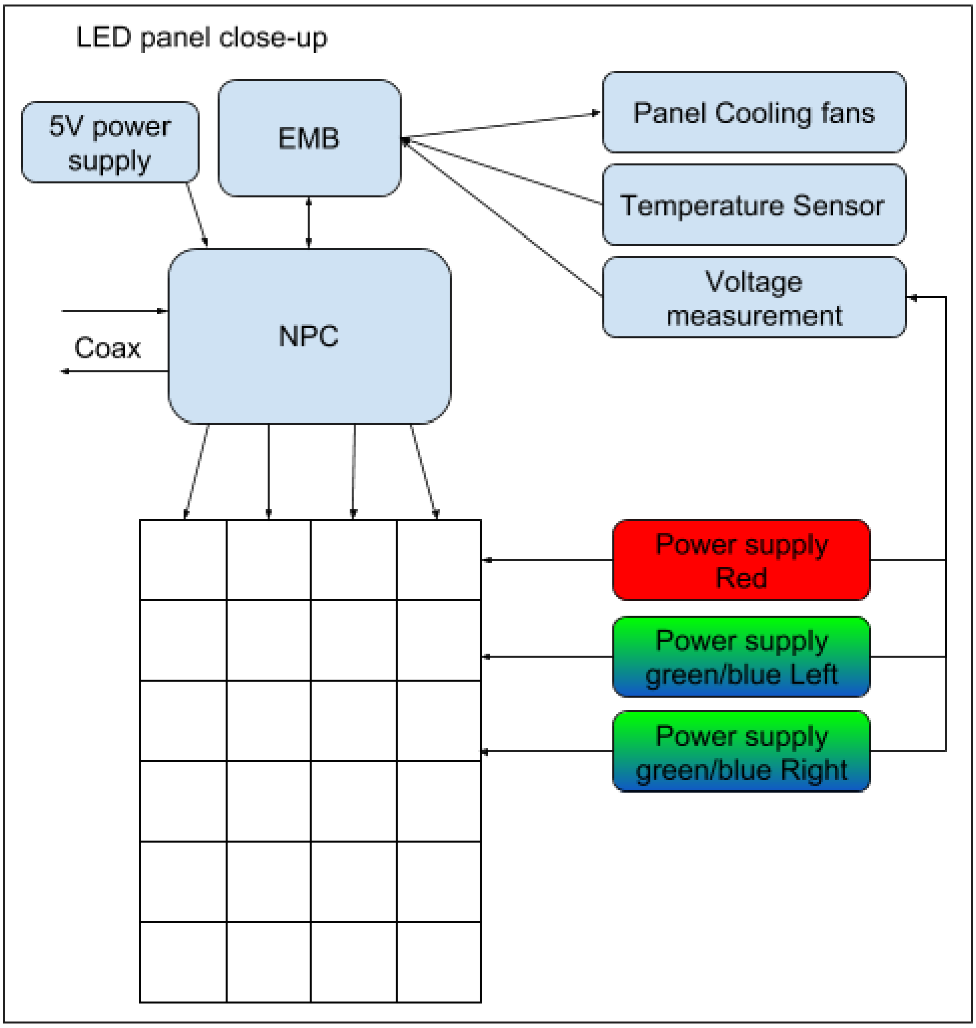

Fig. 2: close up of one panel of the LED screen

Failure can occur in virtually every part of the LED screen, but often happens in the power supplies. Power supply failure has a reasonably big impact on the functioning of the screen, but is easy to repair by replacing the power supply. Jan mentions that on site it is very easy to figure out which power supply has failed, as that specific power supply has a noticeably higher temperature than the others. Tom and Jan have the impression that in hot weather, often as soon as the sun starts shining more intensively, power supplies start failing one after the other, in a higher frequency than usual. Most of the broken power supplies show extensive corrosion at the exhaust opening of the cooling fan. Tom and Jan are convinced that this is because in winter the housing becomes cold enough to cause condensation. Other failures that can occur, are for example that water leaks into the screen which cause LED modules to fail. According to Tom and Jan measuring whether water is leaking into the screen would not be useful as it necessitates a lot of measurement equipment and does not give useful information for preventive maintenance methods. Other failures can include disconnected/broken cables or malfunctioning brightness control.

As of now, every panel in the screen screen is equipped with a temperature sensor, and the voltages of every power supply can individually be monitored. In the current hardware and software there’s still place for another temperature sensor and 2 humidity sensors. It is possible to remotely read out the sensors, meaning that temperature per panel can be monitored from the office. This functionality is however seldom used, because the repairmen see that the screen is broken by looking at the live stream. In addition, every screen has an AMX processor, this processor is for example able to regulate the brightness of a screen with input from an external ambient light intensity sensor.

Appendix B: Conversation with Jan Löbker May 29th 2018

On May 29th 2018 a conversation was held with Jan Löbker, Sr. Operational Project Manager at Hecla Professional BV. In this conversation he elaborated about the extent of the corrosion in the power supplies. This winter a trial was held with the ventilation of the cabinet that holds the electronics, including the power supplies. During the winter this ventilation was switched off, to prevent humid air from entering the cabinet. According to Jan, this has proven quite effective until now, a smaller number of power supplies has been repaired than before. In winter the heat of the electronics causes any humidity to evaporate and the humidity inside the cabinet will decrease.

Previously another trial was held with adaptive ventilation control, using the temperature sensor in the panel to regulate whether the fan should be on or off. This was however not successful because the panels would crash significantly often while this trial was running. The trial was therefore ended. The exact cause of the crashes is unknown, but it most probably has something to do with the bandwidth of the communication channel between the panels and the processor that centrally regulates the cooling fan function for the different panels

During this conversation also the classification of the failures from the maintenance records was discussed. Here it became clear that “tile defect” is for 90% caused by water damage in the LED tiles. Every panel consists of 24 separate ‘tiles’ which can be replaced individually. These tiles are screwed into the panel from the front, and are sealed with a rubber gasket. This gasket however sometimes leaks and enables water to enter the tile, causing water damage to the tile. The water damage can induce single pixel failures, pixel discoloration, or whole tiles to be turned off. Detecting the presence of water is not hard, however implementing this in every tile would be quite involved and costly as a single screen consists of anywhere between a few hundred and a few thousand of these tiles. This makes it an unviable failure mode to handle with PHM. instead of trying to predict or detect this, it would probably be more cost and time effective to invest in improving the water tightness of the tiles.

Appendix C: Maintenance Record Classification

Below a condensed version of the maintenance record classification can be found. The classification was done one by one, the maintenance instances could be shown per day, but this would take up a lot of space.

month	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
year	2014	2014	2014	2014	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2016	2016	2016
Schiphol	3	2	1	2	2	0	6	1	3	1	3	3	4	3	2	3	1	3	4
Zevenhuizen	0	1	1	0	0	0	0	0	1	0	2	3	2	1	0	0	0	1	3
Delft	0	2	0	2	2	1	0	0	1	2	1	3	4	2	3	3	0	2	0
Leiden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vianen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zaltbommel	0	0	0	0	0	0	0	1	1	0	2	0	0	0	2	2	0	3	0
Coentunnel	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	4	0	0
Dordrecht	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Watergraafsm	0	0	3	0	0	0	0	1	1	1	1	1	0	1	0	1	0	0	0
Rotterdam	0	0	0	4	0	0	2	1	0	2	1	0	0	0	1	3	3	3	0
Amersfoort	0	0	1	0	0	0	0	0	0	1	0	2	0	1	0	0	1	2	0
Nieuwegein	0	0	0	0	1	0	1	0	0	1	1	1	0	0	0	2	0	0	0

Monthly classifications from september 2014 till march 2016

month	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
year	2016	2016	2016	2016	2016	2016	2016	2016	2016	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2018	2018	2018
Schiphol	2	1	3	0	3	3	0	0	2	1	6	5	3	4	4	2	5	2	3	4	1	2	3	3
Zevenhuizen	1	1	2	1	3	2	1	0	0	1	0	1	1	1	1	1	2	0	2	1	0	0	1	0
Delft	1	2	1	0	1	1	4	2	2	0	1	3	1	2	0	0	1	3	4	4	2	3	1	1
Leiden	3	1	0	1	0	3	0	3	1	0	0	1	0	0	1	0	0	0	0	2	1	3	3	1
Vianen	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	3	1	0	0	0	0	0
Zaltbommel	3	0	0	0	1	2	2	1	0	1	2	1	0	1	2	0	0	0	0	0	0	0	0	0
Coentunnel	0	0	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0
Dordrecht	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4	1	3	3	2	1	2	1
Watergraafsm	0	1	0	0	0	1	0	2	0	0	1	2	1	3	0	0	0	0	5	1	1	0	0	0
Rotterdam	1	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	0	0	1	1	1	0	2	0
Amersfoort	1	1	0	1	0	0	0	1	0	0	1	0	0	1	2	0	0	0	0	0	1	1	0	0
Nieuwegein	0	1	2	1	0	2	0	1	0	2	1	1	1	1	1	0	1	2	0	1	0	1	0	2

Monthly classifications from April 2016 till march 2018

	Power Supply	Power supply	Cabling	Tile defect	Maintenance	undeterminec	Other	Addressing of	NPC	Water Damag	Power Surge	Brightness Co	AMX
Schip	39	3	0	60	3	9	0	7	1	1	0	2	1
Zever	20	3	1	9	3	5	1	0	2	0	0	3	3
Delft	12	0	0	39	2	8	4	0	1	3	0	1	1
Leide	0	0	0	11	2	2	1	0	6	0	1	2	0
Viane	4	0	0	0	0	2	0	0	4	0	0	0	0
Zaltb	6	1	0	6	1	3	4	0	1	0	0	3	4
Coen	3	0	0	3	1	3	2	0	3	0	0	1	1
Dordr	2	0	8	0	0	10	0	0	0	0	0	2	0
Wate	15	0	0	2	3	7	2	0	2	1	0	1	1
Rotte	7	0	0	6	1	8	3	0	1	0	1	5	1
Amer	4	1	0	5	2	3	1	0	0	0	2	0	0
Nieuw	7	0	0	15	2	0	2	0	1	0	0	2	2

Failure mode classification per location

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