Development of a smart multipurpose light therapy device to improve well-being, performance, and safety of long-haul truck drivers

by

Tuan Minh Dinh Van

(2666466)

Project supervisors: K. Baraka,
B. Chandrasekaran,
I. Gerostathopoulos,
F. Massacci,
K. Tuma

Project members: T. Blom,
I. Ristova,
S. Šišić,
T.M. Dinh Van

2022-07-06

Submitted in partial fulfillment of the requirements for the Bachelor of Science in Computer Science

Development of a smart multipurpose light therapy device to improve well-being, performance, and safety of long-haul truck drivers

Tuan Minh Dinh Van
Vrije Universiteit Amsterdam
Amsterdam, The Netherlands
t.m.dinhvan@student.vu.nl

ABSTRACT

Problem. Long haul truck drivers with night shifts commonly experience health problems as a consequence of irregular sleep and sitting in the same position for large parts of the day. Many of these drivers report driving performance problems as a result of compromised sleep. Additionally, many of these drivers report back pain and strained eyes. All the aforementioned issues influence the general safety of the roads. *Goal.* This paper describes our attempt at creating an easy-to-use, multipurpose light therapy device tailored for long-haul truck drivers that can increase well-being, performance, and consequently safety on the road. *Solution.* The available literature suggests that many of these health problems can be alleviated using ice blue (480 nm), deep red, and (near) infrared light therapy (605-1070 nm). An ESP32 microcontroller was programmed to control the lights in such a way to help drivers with various problems they experience. The blue light is used as a wake-up light and as a light to keep the driver awake in the absence of natural light. The red can be activated with IR therapy presets to treat pain, and eye strain and to improve sleep quality.
Results. The prototype successfully delivers the core functionality of the final product. Furthermore, the prototype can be controlled using a mobile app built with React Native, and using Bluetooth Low Energy to communicate with the device.
Conclusions. Available literature and results of early testing suggest the usefulness of the device for truck drivers. However, field studies should be conducted to confirm this.

1 INTRODUCTION

In the past decade, road freight has drastically increased and amounts to close to 80% of the EU's inland freight transport. With the increase in demand, there is a driver shortage that continues to be a major problem for the logistic companies and the economy. One of the largest issues influencing the driver shortage is the truck driver lifestyle, where drivers face chronic sleep deprivation and body aches. These side effects can make drivers more prone to accidents on the road by affecting them physically and mentally. Further research needs to be done on solutions referring to these issues, considering that a large portion of traffic accidents around the world are linked to inadequate and irregular sleep and additionally, a solution would benefit the road transport sector.

In light of this, this paper describes a two-part light device that has multiple applications, with the two main ones being: relieving pain with infrared light therapy and stimulating alertness with blue light exposure. The device is accompanied by a mobile application that allows more optimal usage and adds extra features to the system.

2 PROBLEM DESCRIPTION AND RESEARCH QUESTIONS

2.1 Problem Description

There are many problems that professional long-haul truck drivers (TDs) face due to their line of work and the current state of the transportation industry. Because of the nature of their job, among others, they often suffer from chronic fatigue, depression, obesity and social isolation. Because of the stressful work environment, the urgency of their job, and low pay, their overall life quality ranks low compared to other jobs. However, one of the most prominent issues among the majority of TDs is sleep hygiene. Studies show that the majority of TDs suffer from some sleep-related problem. Most common are sleep apnea, sleep-disordered breathing, sleep debt, or simply an irregular sleeping pattern that consequently influences one's circadian rhythm [21]. All of these issues lower the life expectancy and quality of life of professional TDs.

One of the consequences of the aforementioned problems is the self-medication of TDs. Research shows that drug use was twice as likely for drivers who had the greatest problem in managing fatigue [17], and those would usually be psychostimulants used for reducing sleepiness during work [18]. TDs getting paid on a payment-by-result basis increases the potential for unhealthy driving practices and are more economically incentivized to indulge in risky behavior. On the other hand, obesity was found to be twice as prevalent in TDs than in the rest of the working population [20]. Research shows that TDs with a BMI of 30 or more were found to be significantly more sleepy than the ones with a BMI of lower than 30, and it contributed to a two-fold higher accident rate than non-obese drivers [19].

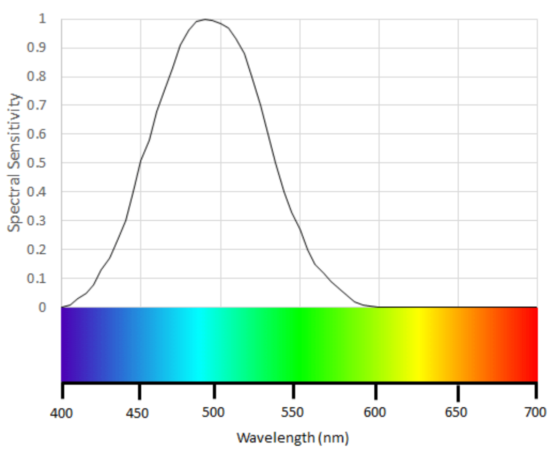
However, TDs are not the only ones affected by this, research shows a strong correlation between sleep-related problems and vehicle accidents [22]. To safely participate in transportation traffic, a certain amount of focus, rest, and reactiveness are required. Sleep-related problems directly affect one's ability to adequately respond to risky situations on the road. Both motor vehicle accidents (MVA) and near-miss accidents (NMA) can be significantly prevented by naps and breaks, but as mentioned before, many drivers choose to ignore regulations in order to finish the job faster.

Based on all this information, we set out to create a multipurpose light therapy device to alleviate as many negative effects of this job as possible, since many of them are deeply rooted in the transportation industry. By improving the well-being and performance of TDs we aim to increase the safety on the roads as well as improve their overall life quality.

How to improve well-being, performance, and consequently the safety of truck drivers using a smart multi-light therapy device?

2.2 State of The Art - Research and Practice

The available literature provides evidence for numerous use cases of 480 nm blue light, deep red, and (near)infrared light therapy. 480 nm light is the most effective light to activate melanopsin photoreceptors, which play a large role in circadian entrainment [1]. These receptors are found in intrinsically photosensitive retinal ganglion cells. Activation of these cells results in communication with the suprachiasmatic nucleus, a region in the hypothalamus responsible for controlling circadian rhythms. Figure 1 shows the response of melanopsin cells to certain wavelengths of light [2].



This image shows the sensitivity of melanopsin photoreceptors to certain wavelengths of light.

Figure 1: Melanopsin spectral sensitivity

Conventional RGB light also contains some light around the peak-response wavelength of 480 nm. However, as shown in figure 2, only the blue and green light activate the melanopsin photoreceptors to some degree, and there is no output at the most effective wavelength [3]. Hence, for a smart light designed to influence your circadian rhythm, LEDs with peak output at 480 nm are better suited. Such LEDs have a higher melanopic ratio, meaning that they provide a larger biological effect at the same level of light output.

Research has shown that nocturnal blue light exposure while driving decreases the number of mistakes made (number of inappropriate line crossings) [5]. Another study examining the effect of blue light on nighttime driving performance found no significant effect on driving simulator measures, subjective sleepiness, and salivary melatonin levels, but did find significantly faster reaction time in the blue light group vs the red light control group [6]. The first study used a luminance in the order of 20 lux while the latter used a blue light of only 1 lux, which might explain the difference in results.

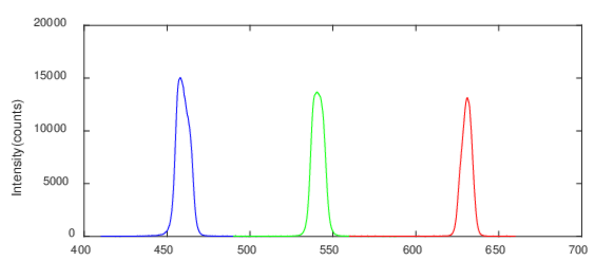
Light exposure during the last 30 minutes of sleep, also known as dawn simulation, similarly has promising effects. In a randomized clinical trial, people who were administered dawn simulation reported significantly better sleep quality and higher ratings of alertness [7]. The experiment also showed improved cognitive performance (a greater number of additions) and faster reaction times. Another study showed the beneficial effects of a wake-up light for children and adolescents [8]. Students awoke earlier, easier, and felt more alert after waking up and during the second lesson at school. Appropriately timing light exposure can be used for circadian entrainment, meaning advancing or delaying the sleep-wake cycle, which can be very useful for shift workers, people traveling to different time zones, or other individuals who want more control over their circadian rhythm [13]. Deep red, near-infrared (NIR), and infrared light also have numerous interesting effects on the human body. One of these effects is significantly reducing the severity of chronic low back pain, with no adverse effects observed after the treatment [9][10]. Furthermore, morning exposure to deep red light improves declining eyesight [11]. Just three minutes of exposure to 670 nm light in the morning once a week lead to an improvement in color contrast vision of 17%. There is also promising research regarding the use of NIR to treat dry eyes [12]. NIR light therapy appears to be “safe and beneficial” for this use case. Additionally, 30 minutes of deep red light therapy at night improved the sleep quality, melatonin levels, and endurance performance of Chinese female basketball players [14].

The wide range of use cases of these kinds of lights suggests that many types of people could benefit from a smart light that can produce them. Blue light exposure at the right time can be used to improve one’s circadian rhythm, sleep quality, cognitive performance, and driving performance. Furthermore, properly timed exposure to deep red and (near)infrared light can be used to improve declining eyesight, alleviate back pain, and treat dry eyes. Aside from truck drivers, possibly others could benefit from a smart light like this since there seem to be many different use cases.

In table 4 the features of our product are compared to the features of some of the competitors.

2.3 Unique Value Contribution

As showcased in the previous section, we did a comparison of already existing similar products on the market. All of them have only one of the two lights we provide and serve a single purpose.



This image shows the output spectrum for regular RGB LED light.

Figure 2: Wavelengths of RGB light

Table 1: Classification of Competing Products

Tool	Company	480nm	Wake-up	Adj. color temp.	(N)IR light therapy	Auto on	Control with smartphone	Price €
Bluewake	Bluewake	✓						550
goLITE BLU	Philips	✓						79.99
Sleep & Wake-up	Philips		✓	✓			✓	219.99
HAPPYLIGHT	Verilux			✓			✓	69.99
SafeHaul	SafeHaul	✓	✓		✓	✓	✓	150

SafeHaul is specifically targeted at long-haul drivers, meaning our product caters to someone who spends a lot of time in the vehicle, works in extraordinary conditions, and is susceptible to many mental and health-related problems due to their line of work.

When it comes to the hardware of the product, SafeHaul is built for vehicle use. It is very portable and compact, which means it can be easily handled in the cabin and other small spaces. The NIR light therapy part is not bulky, unlike other products that serve the same purpose. The "blue" device is easy to integrate into the truck dashboard, it does not require an even surface to be stable, but is instead shaped as a phone, so it can be attached to an already existing phone or GPS holder. Another important feature that sets it apart from the competition is that the whole device can be charged in the vehicle, even without traditional power outlets available.

As for the software functionality of SafeHaul, it utilizes the 480nm ice blue light which is the most effective wavelength for regulating people's biological clock. It promotes alertness when used while driving and mimics the sunrise effect when used in wake-up mode. It gradually increases brightness up until the alarm is set so that the user can get the beneficial effects of natural light even when it is not available (wake-up during the dark hours). There are 2 modes of the "blue" device that the user can choose from. The first one, automatic, doesn't require any input from the user. The device detects the change in light conditions in its environment and automatically adjusts the brightness to the most optimal level. The second one, manual, allows the user to choose the preferred brightness at any given moment either with the buttons on the physical device or through the application. The application is another key value contribution that gives the user complete control over the device in an easy and intuitive fashion. It lets the user set up a wake-up time for the alarm and input their driving schedule, which allows the device to automatically adjust the brightness of blue light based on the time of the day and whether the user is supposed to be driving or not. The application also allows preset modes for NIR light, which makes it easier and safer for the user to utilize light therapy to relieve muscle pain.

All in all, our product offers an easy-to-use and intuitive 3-in-1 experience that no other product on the market currently does and is more affordable than any other similar product.

3 CUSTOMER IDENTIFICATION AND VALIDATION ACTIVITIES

3.1 Validation Activities

In order to gather all the necessary information and get insight into the industry that can not be obtained from the literature review, we decided to use interviews as our main validation activity. The decision was based on economic accessibility and the flexibility that natural language provides. Furthermore, since the validation activities took place before the prototype testing, focus groups were eliminated as a viable means of gathering feedback. It was also decided that a questionnaire would provide a black and white and insufficient representation of user needs, while for this project we were looking for nuances that could be followed up on in real-time. It is also important to take into account that the end-user might differ from the buyer, therefore, we also decided to widen our scope of interviewees.

At first, we conducted some research into different types of truck drivers. The two main groups that were observed were (i) those who own their own trucks and work as freelancers, and (ii) those that work for a company that owns trucks. It was concluded that the main difference between the two would be that the first ones value their own vehicle more, therefore take more care in maintaining it and avoiding any kinds of collisions, even the minor ones. When it comes to the second group, the insurance of the company covers their truck damages, making it a lesser concern in comparison. That could indicate those truck drivers who own their own vehicles would be more inclined to take better care of the truck.

In total, 3 interviews were conducted, 2 of them with professional truck drivers and 1 with the truck company owner. There was also an intention to speak to a representative of a truck manufacturing company, however, considering the time limit and the scale of our company it turned fruitless.

Some useful insights that we gained were, that while the drivers are on the road, they are not permitted (physically and sometimes legally) to make any unplanned stops, except for the truck stops and a few other facilities catering to them. Based on that, it was decided that an adequate place to advertise and sell our product could be a truck stop with a high density of our target customers at one place. Another piece of information to take into account is that the truck drivers are usually paid per kilometer, therefore, the rest and sleep time is unpaid. In general, the daily driving time shall not exceed 9 hours [23]. To check if the driver complies with the rules, there is a device called a tachograph fitted to a vehicle, that automatically records its speed and distance. If the information from the device does not correspond to the regulations, the truck driver will be fined. What we found out from one of the interviewees is that it is sometimes more profitable to not comply with the regulations and pay the fee if caught, than to follow the regulations at all times. This shows a very big gap between the transportation regulations and actual working practices that puts many drivers and other traffic participants at risk. This information shaped another motive: the creation of a device that would aid truck drivers' well-being even in unsafe situations.

3.2 Customer Personas and Usage Model

We created in-depth customer personas [Table 2] based on the research done about the demographics of truck drivers. This gave us useful insight into their buying power, potential physical and mental problems, and family situation. All of those factors influence the further development of the product.

When defining use conditions for our product, portability and reliability were found to be the most important factors to take into account. Since the product is intended specifically for in-vehicle use, it should be compact and mobile. From the t activities phase, it was extracted that the product should be easily transported in a backpack or a bag and easily stored in a drawer or a cupboard (storage space available to truck drivers while on the road). This also meant that there was no need to include weather protection on the device as it is intended for indoor use only. It was also taken into account which kinds of power outlets would be present in the truck, so the product should be able to charge through a 24V truck power outlet. The "blue" device has to be attached somewhere on the dashboard for the most optimal results, therefore, it should be of standard phone size, so the customer doesn't need any special equipment to mount it except for already existing phone and GPS holders. Since the lights also generate some heat (especially the NIR), the material for the product had to be heat-resistant (we chose to use aluminium for the prototype). To ensure easier handling of the "blue" device among other components on the dashboard, it had to be powered by the battery, to create a wireless setup. Based on the demographic of our target customers, an application accompanying the device had to be straightforward and easy to navigate. That entails an intuitive user interface, focusing on the core features and keeping it simple so as to not clutter the user with unnecessary actions. On top of that, developing a cross-platform application both for Android and iOS improved the overall user experience and makes the device accessible to a wider range of customers.

The context diagram (Figure 3.) shows how the system is intended to interact with the environment and the concept diagram (Figure 4.) aims to show the system itself, and its functionality, starting from the core ones in the center and expanding to the higher-level functionality with every circle.

For the user onboarding process, we have developed 3 modes of action:

Outstanding: A live demonstration of all the product features at a conference or a symposium. This will bring the product closer to the customers and show them all its functionality in real-time, both with the physical device and the application.

Target: A prerecorded video demonstration as a tutorial on how to properly use the product and the application. This provides the user with detailed instructions on how to handle SafeHaul. The user can refer back to it as many times as needed. *Minimal*: A user manual that in written form guides the user on how to utilize the product in addition to the in-application tutorial. The user can refer back to it as many times as needed.

All the requirements are described in the Requirements table in the Appendices 17. Additionally, a functional decomposition diagram 5 where you can see an overview of the function of the system and its sub-functions.

3.3 Societal and Legal Constraints

The only legal constraint regarding the blue light device, according to Regulation no. 48 of UNECE [27] is that the light emitted from the device shall not cause discomfort to the driver while driving. According to studies the light emitted from our device does the opposite, it helps the driver with alertness and focus during driving. To confirm this there needs to be approval acquired from a specialty

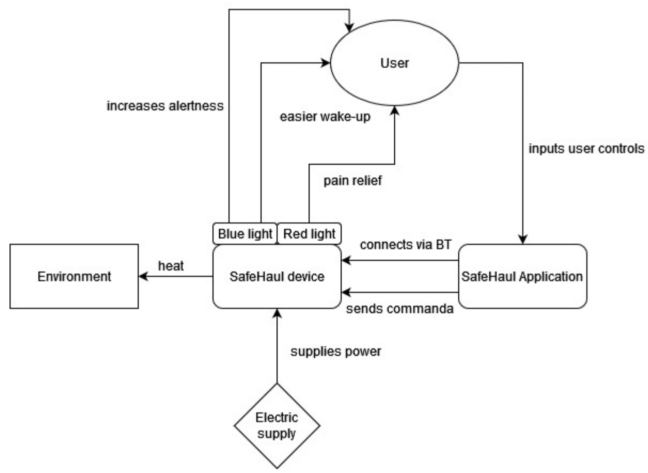


Figure 3: Context diagram

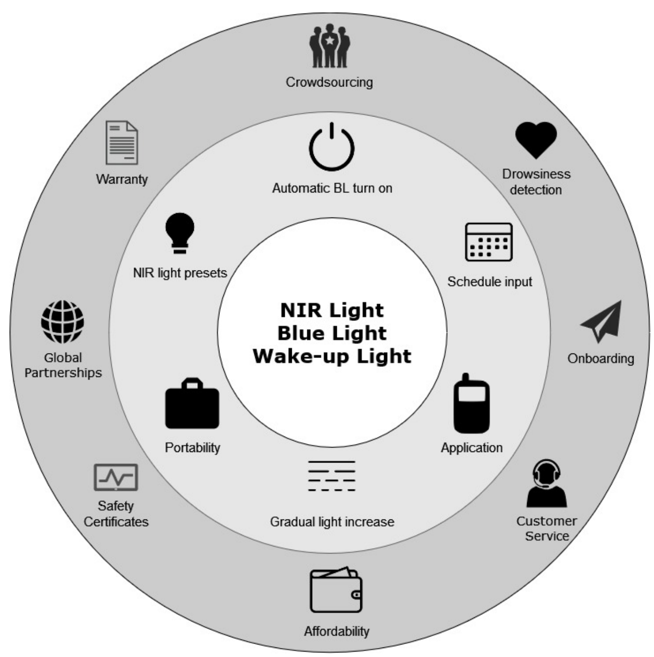


Figure 4: Concept diagram

Table 2: Customer personas

	Luke	Marvin	Saki	Persona 4
Gender	Male	Male	Male	Male
Age	22	36	43	57
Level of education	Finished high school	Some college	College degree	Finished high school
Income (€)	25,000 - 35,000	35,001 - 55,000	35,001 - 55,000	55,001 -75,000
Marital status	Never married	Married	Married	Divorced
Children under 18	0	1	2	0
Years trucking	<1 to 4.9	5.0 - 9.9	10.0 - 19.9	20 - 53
Employment	Commercial fleet	Commercial fleet	Owner operator / independent	Owner operator / independent
Driving with a partner	Never	Sometimes	Never	Never
Consecutive days per trip	11 - 16	17 - 22	22+	22+
Days per month away from home	22+	22+	22+	22+
Interest in health material	Exercise on the road How to avoid back and neck pain Alcohol and drug dependence	How to avoid back and neck pain Sleeping problems / sleep apnea Depression	Eating healthy on the road Quitting smoking Sleeping problems / sleep apnea	How to avoid back and neck pain Managing high blood pressure Sleeping problems / sleep apnea

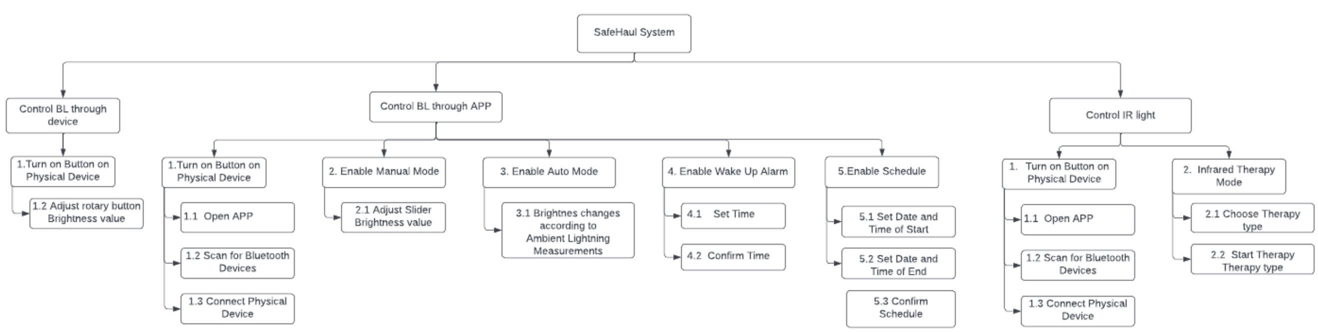


Figure 5: Functional Decomposition diagram

doctor to measure the effectiveness of the product. There are no legal constraints regarding the usage of an Infrared emitting device in a vehicle, it is meant to be done while resting, therefore there is no constraint. Infrared therapy is widely used in today's world and with further research, the right intensity and wavelength that suits our device and comply with the safety standards will be chosen. The user's data that is stored on the device is not sensitive information and with a few modifications of the technical implementation, the data will be stored only on the microcontroller which will not have any access to wifi, therefore preventing any data breaches.

4 TECHNICAL SOLUTION

4.1 Product Architecture

4.1.1 Product schematic. The product architecture schematic above illustrates the relations and connectivities, which are represented by 3 main flows: forces or energy, material and signals or data, between components. Overall, the product will include 3 groups of components, represented as 3 chunks in the diagram.

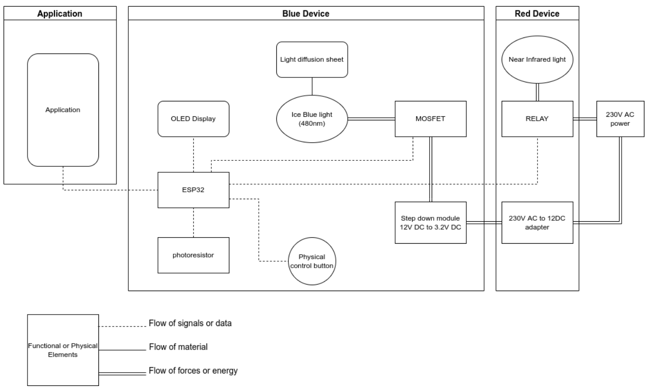


Figure 6: SafeHaul product schematic

Firstly, the power adapter, which is integrated into the “red” device, will be connected to a 230V AC power outlet. It will convert the 230V AC to 12 DC and power to the “blue” device. Then the step-down module decreases the power voltage from 12V to 3.2 V in order to suit the 480nm ice blue LEDs. The MOSFET is a kind of switch that powers and controls the brightness of the ice blue LEDs with the signals received from ESP32. Similarly, in the “red” device, the infrared bulb will be controlled by ESP32 through a relay. Because the infrared light needs an AC power supply with a higher voltage than the blue light, the 230V AC power will be plugged directly into the relay. Thus, the relay can turn ON/OFF the bulb as required by ESP32. The microcontroller ESP32 uses the external power supply in the demo prototype. However, the actual product will be expected to contain a battery inside the device to power not only the ESP32 but also other parts of the device.

Secondly, the signals and data will be transferred by wire and Bluetooth Low Energy (BLE). Microcontroller ESP32 is the unit where information is received, processed, and transmitted to other elements to execute instructions. As mentioned above, ESP32 is able to send signals to MOSFET and RELAY to control the light bulbs. The physical button is used to control the device’s modes as well as adjust the brightness of the lights. When a user interacts with it, the button keeps sending signals to the microcontroller. On the other hand, the photoresistor is a light-sensitive device used to measure the natural light source intensity, which will be sent to the microcontroller to dim or light the lamps. The information about the modes, features, and device status will be displayed on the OLED screen. In addition, modes and features of the product can also be handled by the application on the smartphone via Bluetooth LE connection.

Finally, a diffuser plate will be placed above the ice blue LEDs to avoid glare and soften the blue light.

4.1.2 Geometric layout. While the application can be installed on smartphones and interact with the rest via BLE, the red and blue light will be built as 2 separate devices which connect to each other by a USB slot (type-B or type-C). Because the user will need them for different use cases at different times. Furthermore, the size of the infrared lamp is a lot bigger than the blue one, while they need a small blue device that can fit the dashboard. Therefore, the idea of combining them as the same device was eliminated.

Figure 7: SafeHaul geometric layout 1

As seen in the 3D design, the product follows a minimalistic and compact style. Except for the OLED display and button, all the remaining components of blue light will be covered by a case. Particularly for the blue LEDs, there will be a diffuser plate covered with the function mentioned above. The design of the “blue" device will be in the form of a smartphone. It could be thicker, but should be in vertical form. This eliminates the possibility of difficulty hanging the product on top of the air conditioner, as there are already existing phone hangers on the market. In addition, it is also equipped with a holder so that it can be placed on the dashboard when in use

The red light is designed with a base containing the adapter and relay and connects to the bulb with a gooseneck. When folded, the lamp will have the shape of a vase and the gooseneck will be used as an ear to hang it on. There is a slot in the infrared lamp so that the blue light will be charged and connected to control the red light if it is slid into the slot. This is also a method of protecting the blue device because this product is aimed at portability, compactness and to be carried in a backpack.

4.2 Key Technical Functionalities

With the research we did so far, the ice-blue light (480 nm) and near-infrared light (605-1070 nm) are the two light sources that are most effective in solving the driver’s problem mentioned with the connection help from Bluetooth low energy [7][10][12]. Our goal now is to control them with 2 key technical functionalities: manual and automatic.

The “blue" light can be controlled in both ways. The reason is the blue device would be active while the driver is on their shift, so it

Figure 8: SafeHaul geometric layout 2

is acceptable to let the device work on its own while still providing the best result without any risk of harming the user [16]. However, the manual mode should still appear on both the device and the application so that the driver can adjust the light level as desired, regardless of the ambient light source.

The "red" light, however, should be approached in the other direction, which is half-manual and half-automatic. In fact, finding therapies to heal muscle, eyes, and back function should be proactive by users. And it should only work during rest. Therefore, there will be no red light automatically turning on like the blue one. Even though there is no document warning about side effects as well as health risks when using IR light, the recommended use time is from 10 to 20 minutes [24]. And in order to prevent users from accidentally forgetting to turn off the light, we choose to limit the time of use to 1 time and warn about reasonable usage frequency. Thus, the driver can only use this functionality with some limited modes. Moreover, the application is the only way to control the infrared light. Because it can be only used while not driving, so we can prevent the red light from being accidentally turned on. In order for the product consisting of 2 lights and 1 application to work together, we need the last connected functionality, which is Bluetooth low energy.

The BLE connection is used for connecting the application with the device so that the application can communicate with the ESP32 by sending commands back and forth. The connecting function should be automatically done with a single click on the app and should keep working on every page of the application during the sessions. In addition, data will be encoded and decoded by using base64 during cross-platform communication to avoid unnecessary data errors and lead to better interoperability [25].

4.3 Technical Solutions

Various information is displayed on the OLED screen see figure 9 and figure 10.

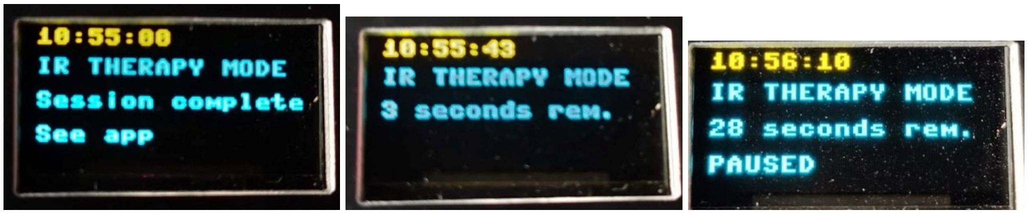
In shift mode and in manual mode the display shows the following information from top to bottom: The current time and the ambient lighting level, which is measured with the photoresistor. The alarm time for the wake-up light Seconds until the wake-up alarm The current BL brightness level and the mode. The rectangle around "shift" indicates that the 9-hour shift, which started at the wake-up time, is currently in progress. A bar indicating the BL brightness level. In IR therapy mode, the OLED display shows the following information: The current time The current mode One of the following: Instructions to start the mobile app OR The remaining time for the IR therapy session, and an indication about if the session is paused.

The esp is programmed with MicroPython to support BLE commands shown in table 3.

To control the BL, the esp32 uses PWM dimming at 30000hz to control a MOSFET module that is connected to the LED's. This high frequency was chosen to avoid flickering caused by dimming and to avoid the coil whine of the step-down module that regulates the voltage and current for the LED's. The digital to analog converter of the ESP32 has a resolution of 16 bits which means there are 2Î6=65536 different levels of brightness. To control the infrared light, the ESP32 controls a relay that turns the power for the light on or off. In a future version of the device, an AC dimmer can be used to partially turn on the light, which could be useful in specific IR therapy presets. The output of the photoresistor is measured with the analog to digital converter on the ESP32. The ADC of the esp32 has a resolution of 12-bits, which means that we can measure 2Î2 = 4096 different levels of brightness. The prototype is configured to connect to a Wi-Fi network at boot and then retrieve the time from the NTP host pool.ntp.org. In case one of these fails, they are retried a few times and the status is shown on the display and printed to the console.

For the prototype, persistent storage was implemented in Micropython by using the file system. Settings are each stored in their own file in a folder called "settings". The filenames are the keys, and the content of the files stores the value. Storage-wise this is not the most efficient solution, but for this purpose In the MicroPython code, the function getSetting takes two arguments: the key and a fallback value that's used when the setting is not saved yet in the persistent storage of the ESP32. The function setSetting takes as arguments a key and a value. The wake-up light is implemented in such a way that it overrides other modes when it is time to wake up. This was designed like this to ensure that it is not possible to miss your alarm by not having the right mode enabled on your device. The wake-up light mode is configured to gradually increase the brightness (linearly), starting 30 minutes in advance, until it's at full brightness at the time the alarm is set. Afterward, it remains at this brightness for 5 minutes. The MicroPython code can be found on https://github.com/thim0o/Pycharm-MicroPython

The two mobile apps are made using the React Native framework that is based on Javascript and enabled us to build a cross-platform app. Currently, there are two versions of the App that will be compared for AB testing purposes, in order to gather feedback from different groups of potential users about design choices, colors, buttons, and such. The implementation of the two apps can be seen in the figures in the Appendices. The Android version 14 of the App is made on one scrollable screen that contains all of the components: Connect, Driving Mode, Wake-Up alarm, Schedule, and Infrared Therapy. Furthermore, it has the functionality to connect to a Bluetooth device and to automatically pair and connect to the ESP32 microcontroller which allows it to send



(a) Poor **(b) Average** **(c) Great**

Figure 9: The display in IR therapy mode

(a) Poor **(b) Average**

Figure 10: The display in manual and shift mode

commands for both the BL and IR devices. For example, whenever one of the confirm buttons is clicked or the slider for the Manual mode is moved, the microcontroller receives a signal with all the information needed to execute the corresponding command on the device. This information includes the value of the intensity of the BL, date and time from the DatePicker, duration of the IR therapy and on/off values for the different modes. This is established by using the Bluetooth Low Energy '@react-native-ble-plx' library to communicate with the ESP32, which was the most challenging part of the implementation. Other libraries and tools that are used are '@react-native-community/datetimepicker', '@react-native-countdown-component', react-native built-in components, and react native elements UI toolkit. The IOS version 1516 of the App is made to have some different design choices and a react navigation stack with touchable elements that have routes in order to navigate to different screens and pass data between each other.

4.4 Meeting the Requirements

From the requirements stated in the Requirements table in the Appendix 17, we can see from the rightmost column that our prototype meets a majority of the requirements, along with some that are partially met or not met at all. The functional requirements that we have for the BL device prototype (1 - 7) are met by having a manual and App control functionality, with automatic activation according to the ambient lighting sensor, wake-up mode alarm, and schedule mode. The requirements that were not met in this section are regarding the automatic change of brightness according to the ambient lighting and the ability to set the preferences for the wake-up simulation, which are fixed for now. Additionally, the requirement regarding the performance of the BL device during fluctuations of lighting (8th) is also met, by the implementation of an acceptable range plus/minus the threshold.

The requirements for the IR device (9-11) that are met provide the ability to choose the duration of the IR therapy from a list of constrained options that meet the safety standards, therefore preventing the situation where the IR device is left turned on for a longer period of time.

One functional requirement that was not implemented for the prototype is the Smartwatch drowsiness detection (12th) but is considered in future plans.

The rest of the requirements stated (12-21) are mostly non-functional requirements regarding the quality, security, and performance of the system. The current prototype does not comply with the portability requirement and is not the ideal size, nor does it have the best software architecture or best data security and UI. But it does use the latest, stable frameworks for the functionalities and Application, which have a straightforward and easy-flow along with visual feedback of the status on the device display screen as described in (4c).

Platform compatibility is achieved by using React Native for the app which is compiled to code for both IOS and Android and contributes to the maintainability of the Application. The requirement for saving the Application data is met by storing the preferences on the ESP32, and they are not lost after disconnecting the application or after the device loses power. The Response Time for the Bluetooth and the processing time for the commands is very low (near-instantaneous), which was shown during the demo of the prototype. And lastly, the design of the App is very minimalistic and not crammed with information, which for now provides a decent user experience as can be seen in the APP implementation in (4c).

4.5 Failure Modes

See Table 4.

Table 3: BLE commands supported by the device

Command identifier	**Example command**	**Effect**	**Response**	Note / Special
set alarm	set alarm 9:30	Set the wake up light alarm	alarm set	"set alarm -1:-1" to disable
start ir	start ir 15	Start an ir therapy session of 15 seconds	15	Responds with the number of seconds remaining
stop ir	stop ir	Stop the ir therapy session	stopped ir	
pause resume ir	pause resume ir	Pauses or resumes the IR therapy session	paused / resumed	
set brightness	set brightness 70	changes the shift brightness to a % value	set brightness to 0.7	
Other	test	None	"command not recognized: test"	Returns an error when the command is not recognized

Table 4: Failure modes

How the product might fail	What was done to prevent failure
BL flickering when the ambient brightness level fluctuates around the darkness threshold	"Smoothing the measurements of the photoresistor to get more consistent readings.
	Have some space between the thresholds to turn on/off the device.
Losing settings when the device loses power	Various settings are stored in the persistent memory of the ESP32: shift brightness, manual brightness, and the shift/wake-up time
Users forgetting to turn off the IR	IR therapy can only be started with presets that have a fixed duration, so users don't have to remember to turn it off
Missing the wake-up light alarm when the device is not in the right mode	In case it is time to wake up the user, the wake-up light mode overrides the BL brightness set in other modes. This ensures that the wake-up light sequence will never be missed.
A user finds it uncomfortable to look at the blue light	The blue light is diffused to make it easier on the eyes. The brightness can be adjusted by the user.
The BL is on while not needed because there is enough natural lighting	In shift mode the BL will only turn on when there is not enough natural lighting, which is measured with the photoresistor.

5 TECHNICAL EVALUATION

5.1 Off-site Evaluation

The first thing to be tested during this project was a breadboard setup of an esp32 controlling the blue LEDs with PWM dimming. After this started working, the esp32 was programmed in the Arduino IDE to gradually turn on the blue light over a period of 20 minutes. After this was successfully implemented, the code was extended to start the gradual blue light brightness at a certain time. This provided the basics for the wake-up light feature.

To test the wake-up light, it was used in conjunction with a regular alarm to see if it manages to wake up the user in a comfortable way just before their regular alarm. The results of these informal tests were quite promising. During most of these trials, the device woke up the user only a few minutes before the chosen wake-up time when the brightness was around 70& of the configured maximum of the testing setup. On a few occasions, we tested with a considerably earlier wake-up time than usual. In these cases, the prototype also managed to comfortably wake up the user. A handful of trials were not as successful and failed to wake up the user with light. These failed trials occurred almost exclusively when the user went to sleep later than usual, often due to a social event where alcohol was consumed, which might have impacted sleep. While failed trials like this were not common during testing, they highlight the importance of having a backup alarm in case the wake-up light fails to wake up the user. Another thing we noticed during the trials was that more light was required to wake up the user during times with a lot of natural light, such as after multiple sunny days in a row. This corresponds with findings that show decreased light-mediated melatonin suppression in the summer compared to in the winter [4]. It might be possible to work around this issue by adjusting the wake-up light brightness based on the average measured ambient brightness of the last few days or weeks.

In this stage, the ESP32 was reprogrammed using MicroPython. This framework was chosen because of the increased development speed when compared to the C++ based Arduino framework. Before this framework was selected, we researched if there existed libraries to communicate with the other hardware components, which fortunately did exist. At this point, the implementation of Bluetooth Low Energy was started, along with the MicroPython code that handles the incoming commands. Testing commands were sent using the Android app Serial Bluetooth Terminal.

Further testing was performed after a photoresistor was added to the breadboard setup. The photoresistor was used to measure the amount of ambient light, which was useful to determine if the blue light should be turned on while in the shift mode of the product. After observing some measurements some testing was performed with as goal to automatically turn on the light below some level of ambient light. This worked to some degree, however, there was some flickering when the brightness level was around the threshold to enable the light. To solve this problem, a moving average of the ambient brightness was used to get a more stable reading. Additionally, instead of one threshold, two different thresholds were used to determine if the light should be turned on or off. These software changes were sufficient to get rid of the flickering.

When the breadboard setup was done, the components of the BL device were soldered so the prototype could be moved to an encasing. This encasing consisted of two aluminum plates which functioned as the front and back of the device. These plates were cut out of aluminum using a water cutter. After the prototype was moved to this case, some soldering connections were coming loose, which meant that some additional soldering needed to be done. After this resoldering, the prototype was functional again, which shifted our focus on fine-tuning the software on the esp32 and the mobile app.

The mobile application was coded in JavaScript. And the JS framework used is React-native, so the app can be run on both current biggest OS, Android and IOS. Although there are some differences in how the app is rendered, building it this way can save time and still be productive. The main and important libraries that make up this app fortunately are usable on both platforms such as react-native-ble-plx, react, and react-native.

Testing the UI of the app can be done easily with an emulator, however, functions and Bluetooth connection required a real device with a Bluetooth module and the prototype to test. During the development, the code for the prototype and application had some conflicts, but they still work and communicate with each other in the end. To test the Bluetooth connection, the app needed to find a device with a specific Bluetooth name, called 'SafeHaul', then two devices exchanged information about services and characteristics. Based on these parameters, the app was tested by sending a simple encoded command. After that, other commands were added to control the functions of the prototype.

5.2 Demo Scenario

The usage environment of the product is mainly in the truck cabin, therefore, the demo scenarios should simulate the use cases of the product when the driver is driving or living in the cubicles (for example, during breaks or overnight at stations). Assuming that the prototype is demoed in a room, the required conditions for that room are having windows with natural light and curtains to simulate darkness. The "blue" light will be placed on a vertical surface, approximately 49 cm from the participant's eyes and at a horizontal angle of around 25 degrees [6]. Because, in the real use case, the "blue" light will be located behind the steering wheel and somewhere between the dashboard and front air conditioner. Besides, the infrared light can be placed on the table. The participants can interact with the product by using an application installed on a smartphone or using a physical control button on the "blue" light. The scenarios below describe some possible use cases in real life and how the product implements the demo. There are 2 main conditions of the driver that we focus on: while driving and while resting.

While driving:

- Scenario 1: Manually control blue light with the button: The brightness of blue light needs to be adjusted. Maybe it is because it is getting dark or the driver wants more blue light to focus more. He can change the brightness by turning the knob.
- Scenario 2: Control blue light with Auto mode: Switch to the auto mode where the brightness is adjusted based on the natural light source. If the environment is getting dark, the blue light increases its intensity automatically and vice versa. In the demo, the curtains can be closed to simulate darkness.
- Scenario 3: Using the application to control the blue light with more features: Connecting to the device with Bluetooth low energy and controlling the brightness manually by swiping a slider, turning on/off auto mode which has the same result as scenario 2 but on the app. Note: Even though the driver can use his phone to adjust the lights, for safety reasons, he should only use it at the beginning of the shift or when the truck is not moving.

While taking rest:

- Scenario 4: Using the application to set a wake-up time and set a schedule for a shift: The driver takes a nap and wants to set an alarm so that he can wake up on time without having to hear annoying alarms. He also wants to set a blue light schedule for a 9-hour-shift. Setting the light alarm and schedule are features included in the application. In the demo, the audience can experience them with a prepared smartphone.
- Scenario 5: Using infrared therapy by controlling the application: After a long shift, the driver's eyes are strained, and his muscle and back hurt. He decides to choose 1 out of 3 therapies (quick, regular, or deep mode), and presses the button to start, pause, resume or stop the therapy to control the infrared lamp. The duration of quick, regular, and deep modes are 10, 15, and 20 minutes, respectively.

For safety reasons, some functions and features can not be used while driving, such as using the mobile application or controlling infrared light.

6 INDIVIDUAL CONTRIBUTION

6.1 Individual Assessment

1. Wrote the section about product architecture

Schematic: Describe the product architecture with 3 main flows: signal or data, material and forces or energy. It shows the position of each component in the product and how they relate to each other.

Geometric: Convert from schematic to geometric and describe the product's structure in 3D. This part explains decisions on product design and product architecture.

2. Made the schematic of product architecture with the help from Thimo

3. Wrote the section about key technical functionalities This section describes how the main parts of the product are controlled with 2 key technical functionalities. The choices are made on the basis of convenience, efficiency and safety.

4. Wrote the section about Demo scenario

This section describes how to simulate the truck cabin, lighting environment, and how humans interact with the product. It also lists product usage scenarios in the demo session with the relation of the real situation.

5. Helped adding screenshots and video of application for Android of the Technical solutions

6. Wrote a part about application testing of Off-site evaluation

6.2 Group Assessment

Minh In the early stages of the project, I took ideas from other members to develop them to fit our project's goal and contributed to some parts of the canvas and architecture phase. During the demo phase, I had the role of an app developer on android devices. Thimo and I worked together so that the device and the app could communicate with each other using a bluetooth connection. Thimo took care of the device part while I took care of the application part.

Thimo Thimo was the one who came up with the idea of using light with a specific wavelength to improve health with some early research. His main role is to develop the physical prototype. He was also the one who programmed the device to make sure it works as expected. In addition, Thimo also helped me in the testing phase with bluetooth connection

Sofia Sofia has the role of a communicator, contact person in the team to contact the professor, supervisor, electrical team, mechanical team and 3D designer. She came up with ideas about target customers and how to put the product to practice. She also has the role of managing the team's activities. Sofia and Thimo also worked together to develop the demo prototype with electrical and mechanical teams. Although we did not really choose a leader, for me, she is really a leader who can motivate and give advice to team members.

Irena During the concept development stage, Irena was the one who contacted some truck drivers and company owners to interview and give the direction of the product. She also contributed a lot of ideas in the canvas and architecture stage. In the demo phase, she is the interface designer for the application on IOS. Irena and I also worked together to develop features and interfaces on Android version

7 CONCLUSIONS AND WAY FORWARD

So far, the product that we build can solve the problems that the truckers often face. More than that, it has the ability to improve the well-being and performance of truck drivers. This product can be used as a substitute for methods of keeping awake such as caffeine or nicotine as well as restorative methods such as sauna or massage.With the effectiveness studies done and the prototype built, we believe that this product can be manufactured and marketed in the future. Because the ice-blue and infrared lights have many more applications [5][27], more features can be added and the product's market can also expand for more customers. Drowsiness detection with a heart rate sensor is also a feature expected to add for the future product. Besides, the current prototype can still be redesigned to be more compact. The components of the product can be rearranged or changed to be streamlined, such as removing some wires, adding a bigger OLED screen to display more information or expanding more area for blue light. The application can also be redesigned to be more user-friendly. Background running mode could be added to maintain bluetooth connection when the phone is off or the user is using other applications. Anyway, we have achieved our goal for this project and it can be further improved in the future.

8 ACKNOWLEDGEMENTS

We would like to express our gratitude to Björn Singerling, from the VU Mechanical Engineering Lab, for helping us with the product casing, Paolo Massacci, for creating beautiful 3D renders and sketches of the product (see Figure 7. and Figure 8. and Appendix Figure 19. and Figure 21.) and the VU Electrical Engineering Lab for guidance and for providing us with the space to assemble our product.

REFERENCES

[1] Enezi, J. al, Revell, V., Brown, T., Wynne, J., Schlangen, L., & Lucas, R. (2011). A "Melanopic" Spectral Efficiency Function Predicts the Sensitivity of Melanopsin Photoreceptors to Polychromatic Lights. Journal of Biological Rhythms, 26(4), 314–323. https://doi.org/10.1177/0748730411409719

[2] Source: Tian, Xiaobo & Tu, Xingzhou & Junchao, Zhang & Spires, Oliver & Brock, Neal & Pau, Stanley & Liang, Rongguang. (2018). Snapshot multi-wavelength interference microscope. Optics Express. 26. 18279. 10.1364/OE.26.018279.

[3] Miyazaki, Daisuke & Ueda, Kimi & Kawamoto, Soma & Takekawa, Wakako & Ishii, Hirotake & Shimoda, Hiroshi. (2020). An Experimental Study on Evaluating Glare in Blue Light Exposure. 10.1007/978-3-030-20441-9_12.

[4] Shigekazu Higuchi, Yutaka Motohashi, Keita Ishibashi & Takafumi Maeda (2007) Less Exposure to Daily Ambient Light in Winter Increases Sensitivity of Melatonin to Light Suppression, Chronobiology International, 24:1, 31-43, DOI: 10.1080/07420520601139805

[5] Taillard, J., Capelli, A., Sagaspe, P., Anund, A., Akerstedt, T., & Philip, P. (2012). In-car nocturnal blue light exposure improves motorway driving: a randomized controlled trial. PloS one, 7(10), e46750. https://doi.org/10.1371/journal.pone.0046750]

[6] Jo Phipps-Nelson, Jennifer R. Redman, Luc J. M. Schlangen & Shantha M. W. Rajaratnam (2009) BLUE LIGHT Exposure Reduces Objective Measures of Sleepiness during Prolonged Nighttime Performance Testing, Chronobiology International, 26:5, 891-912, DOI: 10.1080/07420520903044364

[7] Thompson, A., Jones, H., Gregson, W. et al. Effects of dawn simulation on markers of sleep inertia and post-waking performance in humans. Eur J Appl Physiol 114, 1049–1056 (2014).

[8] Evantina Fromm , Christina Horlebein , Alexandra Meergans , Marianne Niesner & Christoph Randler (2011) Evaluation of a dawn simulator in children and adolescents, Biological Rhythm Research, 42:5, 417-425, DOI: 10.1080/09291016.2010.525851

[9] Hsieh, RL., Lee, WC. Short-term therapeutic effects of 890-nanometer light therapy for chronic low back pain: a double-blind randomized placebo-controlled study. Lasers Med Sci 29, 671–679 (2014). https://doi.org/10.1007/s10103-013-1378-2

[10] George D Gale, Peter J Rothbart, Ye Li, "Infrared Therapy for Chronic Low Back Pain: A Randomized, Controlled Trial", Pain Research and Management, vol. 11, Article ID 876920, 4 pages, 2006. https://doi.org/10.1155/2006/876920

[11] Harpreet Shinhmar, Chris Hogg, Magella Neveu, Glen Jeffery. Weeklong improved colour contrasts sensitivity after single 670 nm exposures associated with enhanced mitochondrial function. Scientific Reports, 2021; 11 (1) DOI: 10.1038/s41598-021-02311-1

[12] Park, Y., Kim, H., Kim, S. et al. Effect of low-level light therapy in patients with dry eye: a prospective, randomized, observer-masked trial. Sci Rep 12, 3575 (2022). https://doi.org/10.1038/s41598-022-07427-6

[13] Gooley, Joshua J. "Treatment of circadian rhythm sleep disorders with light." Annals of the Academy of Medicine, Singapore vol. 37,8 (2008): 669-76.

[14] Zhao, J., Tian, Y., Nie, J., Xu, J., & Liu, D. (2012). Red light and the sleep quality and endurance performance of Chinese female basketball players. Journal of athletic training, 47(6), 673–678. https://doi.org/10.4085/1062-6050-47.6.08

[15] Girotto E, Mesas AE, de Andrade SM, et al, Psychoactive substance use by truck drivers: a systematic reviewOccupational and Environmental Medicine 2014;
https://oem.bmj.com/content/oemed/71/1/71.full.pdf; ;71:71-76.

[16] Pöysti, L, Rajalin, S., Summala, H. Factors influencing the use of cellular (mobile) phone during driving and hazards while using it, Accident Analysis & Prevention, Volume 37, Issue 1, 2005, Pages 47-51, ISSN 0001-4575, https://doi.org/10.1016/j.aap.2004.06.003.

[17] Ann Williamson, Predictors of Psychostimulant Use by Long-Distance Truck Drivers, American Journal of Epidemiology, Volume 166, Issue 11, 1 December 2007, Pages 1320–1326

[18] Girotto, E., Mesas, A. E., de Andrade, S. M., & Birolim, M. M. (2014). Psychoactive substance use by truck drivers: a systematic review. Occupational and environmental medicine, 71(1), 71–76. https://doi.org/10.1136/oemed-2013-101452

[19] Kushner, R. F., & Foster, G. D. (2000). Obesity and quality of life. Nutrition (Burbank, Los Angeles County, Calif.), 16(10), 947–952. https://doi.org/10.1016/s0899-9007(00)00404-4

[20] Sieber, W.K., Robinson, C.F., Birdsey, J., Chen, G.X., Hitchcock, E.M., Lincoln, J.E., Nakata, A. and Sweeney, M.H. (2014), Obesity and other risk factors: The National Survey of U.S. Long-Haul Truck Driver Health and Injury. Am. J. Ind. Med., 57: 615-626. https://doi.org/10.1002/ajim.22293

[21] Ann Williamson, Predictors of Psychostimulant Use by Long-Distance Truck Drivers, American Journal of Epidemiology, Volume 166, Issue 11, 1 December 2007, Pages 1320–1326

[22] Sleep Apnea, Sleep Debt and Daytime Sleepiness Are Independently Associated with Road Accidents. A Cross-Sectional Study on Truck Drivers, Garbarino S, Durando P, Guglielmi O, Dini G, Bersi F, et al. (2016) Sleep Apnea, Sleep Debt and Daytime Sleepiness Are Independently Associated with Road Accidents. A Cross-Sectional Study on Truck Drivers. PLOS ONE 11(11): e0166262. https://doi.org/10.1371/journal.pone.0166262

[23] Regulation (EC) no 561/2006 of the European Parliament and of the council of 15 March 2006 on the harmonization of certain social legislation relating to road transport and amending Council Regulations (EEC) No 3821/85 and (EC) No 2135/98 and repealing Council Regulation (EEC) No 3820/85 OJ L102/1, art 6, para 1

[24] Kim J, Jung H, Yim J. Effects of Contrast Therapy Using Infrared and Cryotherapy as Compared with Contrast Bath Therapy on Blood Flow, Muscle Tone, and Pain Threshold in Young Healthy Adults. Med Sci Monit. 2020 Aug 3;26:e922544. doi: 10.12659/MSM.922544. PMID: 32745076; PMCID: PMC7425122.

[25] Josefsson, S. The base16, base32, and base64 data encodings. No. rfc4648. 2006.

[26]Tsai SR, Hamblin MR. Biological effects and medical applications of infrared radiation. J Photochem Photobiol B. 2017;170:197-207. doi:10.1016/j.jphotobiol.2017.04.014

[27] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=uriserv:OJ.L_.2019.014.01.0042.01.ENG

9 APPENDICES

Screen recording links
https://www.youtube.com/shorts/E7ygL17bYKQ
https://www.youtube.com/watch?v=9OVrZzpyYO0

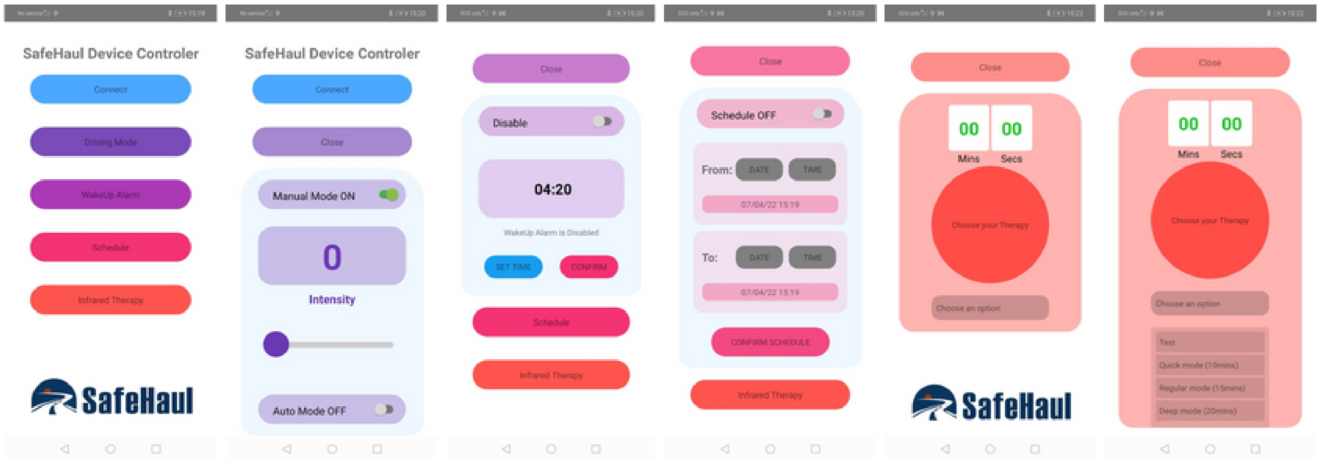


Figure 14: The screens in the android app

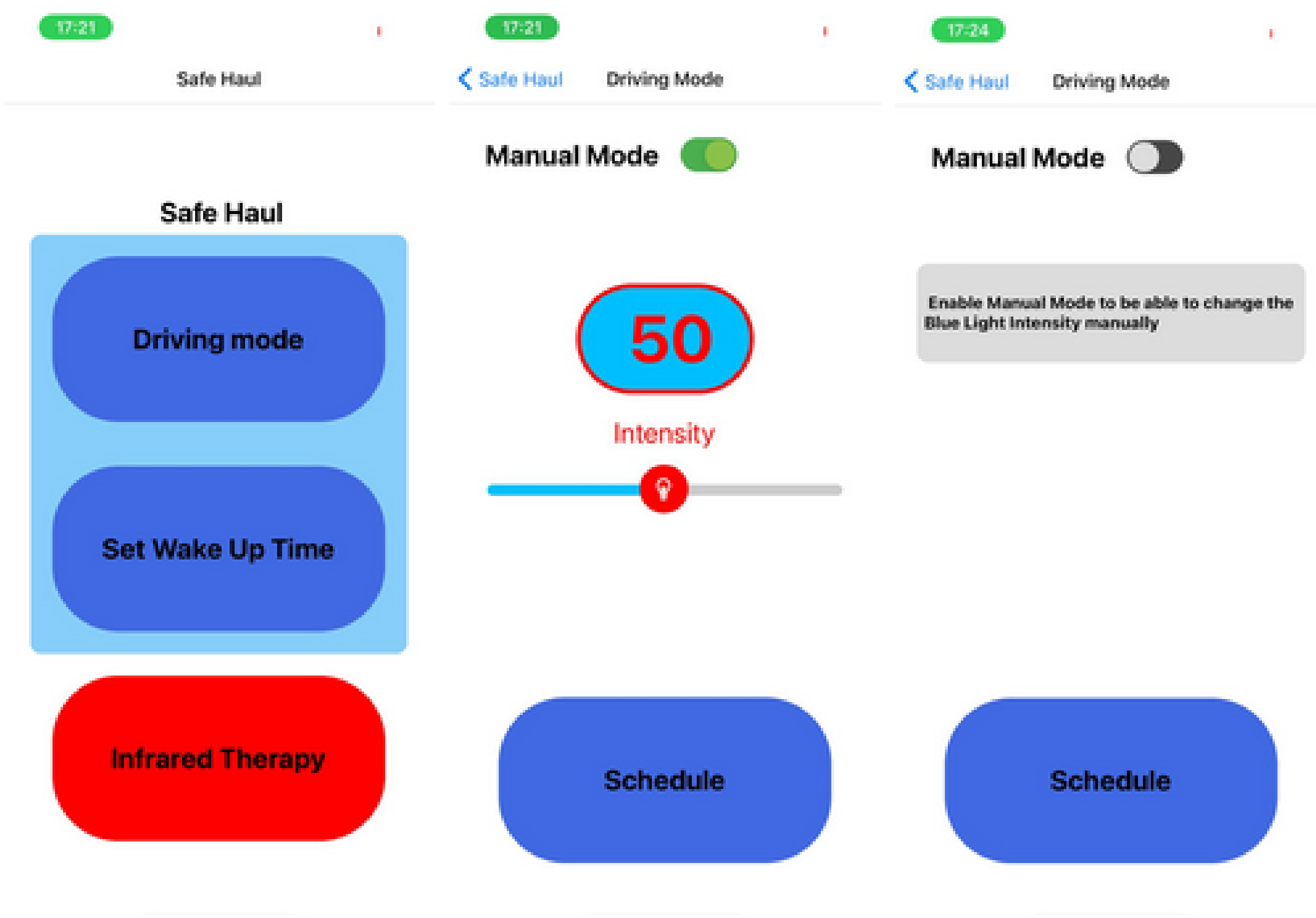


Figure 15: The screens in the IOS app 1/2

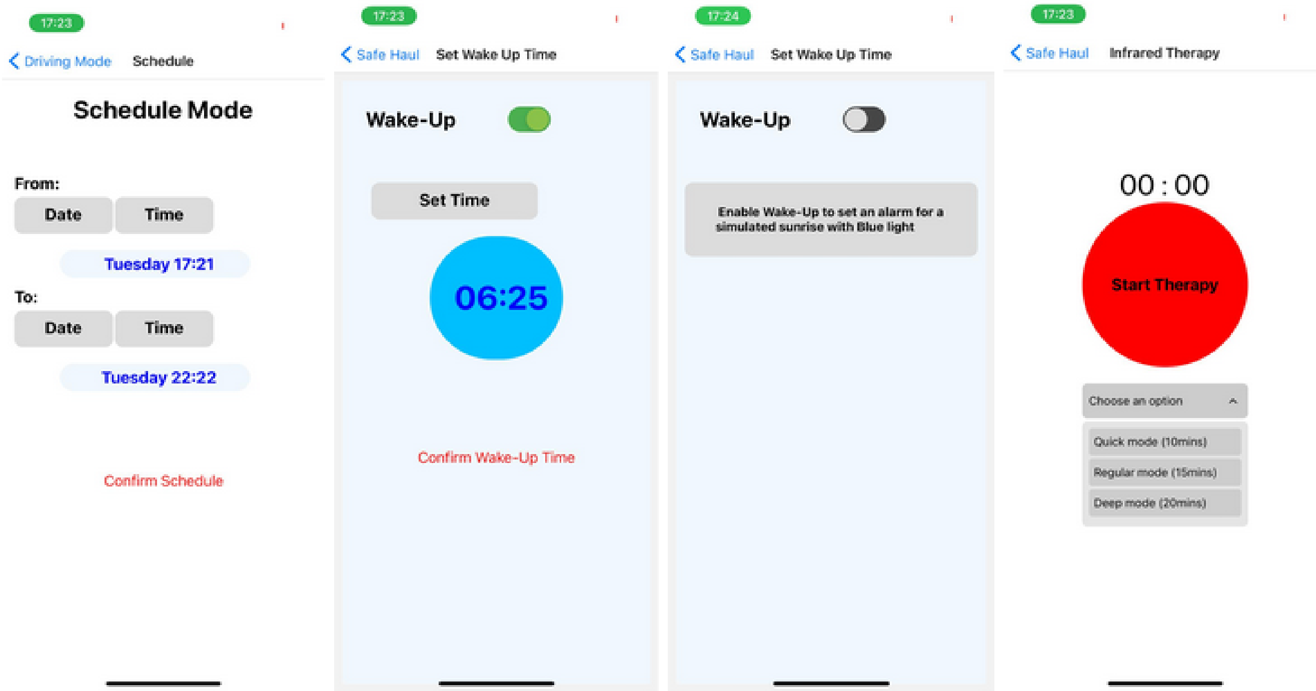


Figure 16: The screens in the IOS app 2/2

Figure 17: Requirements table

Requirement	As a ...	I want	So that...	Met ?
1. BL manual activation/deactivation	user	to be able to turn off/on the BL manually	I can use the BL without any additional equipment	Yes
2. BL manual brightness manipulation	user	to be able to change the brightness of BL manually	I can change the brightness according to what suits me	Yes
3. Automatic activation of BL	user	the BL to turn on automatically when it gets dark	I don't have to touch my phone or device while I'm driving	Yes
4. Automatic adjustment of BL brightness	user	the BL brightness to change automatically according to lighting conditions	I don't have to change the brightness manually	No
5. Wake-Up mode	user	to be able to set an alarm for the BL activation	I can wake up more naturally with the BL sunrise simulation	Yes
6. Preferences of Wake-Up	user	to be able to set the preferences of the BL sunrise simulation(fading duration, min/max brightness)	I can adjust the preferences according to what suits me best for waking up	No
7. Schedule mode	user	to be able to input my shift schedule	I don't have to operate the device/phone for BL use during my shift	Yes
8. BL flickering	developer	to allow smoothing the measurements of ambient lighting and setting distance for the on/off threshold	the BL will not flicker when the ambient lighting is fluctuating around the threshold	Yes
9. IR therapy sessions (purpose)	user	to be able to choose a therapy from different options (range of wavelength)	I can choose the purpose of the therapy (back pain, eyesight, muscle pain, sleep quality, performance..)	No
10. IR therapy session (duration)	user	to be able to choose a therapy from different options (duration)	I can choose the duration of the therapy that suits me	Yes
11. IR safety	developer	to make the IR duration options fixed according to safety standards	the user is not exposed to IR light more than recommended	Yes
12.Smartwatch drowsiness detection	developer	to implement measuring the user's heart rate variability through the smartwatch	the system can alert the user when drowsiness is recognized during driving	No
13. Portability and Compactness	user	to make the device portable and a suitable size	I can move the device with me and fit it in my backpack or the drawer in the truck	No
14. Platform compatibility	developer	to develop an app that would be cross-platform (IOS and Android)	the app is available for the large majority of users and the app is easier to maintain	Yes
15. Response time (Bluetooth)	developer	to establish a BLE connection between the ESP32 and App in a timely manner	the scanning of devices and connection runs smoothly and fast	Yes
16. Response/ Processing time (App)	developer	to implement a robust action-response bond between the ESP32 and App	the commands from the App will be instantly reflected in the physical system	Yes
17.Architecture/Coding standards	developer	to develop a system using standard solutions and modern coding frameworks	life is easier for the development team that will work with the system	Partially
19. Data Security	developer	to allow the functioning of the system without wi-fi, only Bluetooth.	the user's data is not exposed to the internet	Partially
20. Data Storage	user	to have my settings stored in the device	when I turn off my phone/app, the settings that I set before are saved	Yes
21.Minimalistic Design	developer	to design the App without including irrelevant information and visual clutter	the App's cognitive load is reduced and to have a simple and intuitive user experience	Yes
21. Visibility of System Status	developer	to make the App's elements visible and provide feedback on the system status	the user has context-awareness and is informed about what is going on	Partially

Figure 19: NIR light product in use

Figure 21: Blue light product in use