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An IT-solution for Clinical Evaluation of an On-scene Injury Severity Prediction Algorithm intended for Road Crash Victims

Master's thesis in Master Programme in Biomedical Engineering

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Abstract

In Sweden, as in most countries, the accuracy of triage of road crash patients appears to be low. There is a need for new complementary tools to improve the accuracy. An algorithm for On-Scene Injury Severity Prediction (OSISP) of car passengers involved in road crashes has been developed at the SAFER Vehicle and Traffic Safety Centre at Chalmers. The use of this algorithm in the prehospital stage has the potential to become a complementary tool to improve the triage accuracy. In this thesis, an implementation of the algorithm has been developed for use in Android smartphones. The App format has been designed to naturally fit into the normal workflow of ambulance personnel, via iterative refinements considering feedback from prehospital experts. The user is asked to provide Accident Characteristics for the OSISP algorithm to calculate the risk of severe injury, e.g. age, gender, airbag deployment, belt use, environment, type of accident and posted speed limit. According to the calculated risk, an example of how the clinical decision support may look like is presented. The App logs the data to a server via an File Transfer Protocol implementation. Data is sent through a mobile network or WiFi and automatically uploaded to the server when a network becomes available. Based on input from interviews, a possibility to triage several patients at the same time has been implemented. The final solution has been confirmed to appear to be usable in the field by several ambulance nurses. This solution is ready for implementation in a clinical study and evaluation of the OSISP algorithm. If the solution is successfully evaluated, the ambition is to integrate the algorithm in other ambulance ICT-platforms.

Keywords: Prehospital, OSISP, triage, CDSS, mHealth, smartphone, Android

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1
Introduction

Injury is nowadays considered as one of the leading causes of death and disability worldwide, being the main reason among population under 35 years old [1]. Further, traffic accidents are the most fatal type of trauma becoming the sixth cause of global mortality among males and leading to 1.3 million casualties and 45 million people with some kind of disability each year [1]. According to World Health Organization (WHO), up to 2030 an increase of 40% in trauma fatalities is expected [2]. These figures are strongly influenced by developing countries, where the numbers are considerably aggravated due to an uncontrollable rise of motor vehicles [1]. Despite the effort in preventive and awareness campaigns of developed countries to combat this situation and a noticeable decrease of the mortality in road traffic accidents, numbers are still bleak [1]. In Sweden, where 300 people die and 3000 are severely injured each year, this trend is also observed [3].

In the recent past, the effectiveness of trauma centers has been called into question due to the lack of strong evidence in several studies [4]. Subjectively influenced by the limited use of data or restricted criteria, those studies were often excluding patients who died before being transferred to a trauma center. More recent investigations agree on claiming trauma centers to be fundamental to reduce the risk of death of severely injured patients up to 25% [4]. According to the significant effect care provided by such hospitals has on the survival rate of severely injured patients, direct transport to a trauma center is crucial. This hypothesis is supported by the fact that approximately 50% of trauma deaths occur within the first hour while 20% of patients die between the first and sixth hour after the injury [5, 6].

Minimizing the time for adequate treatment has been demonstrated to reduce subsequent mortality and mitigate further disabilities [6]. However, sending all the patients to a trauma center does not seem to be the optimal solution since some of them might not require such a medical assistance. In addition, this would overburden trauma centers and deprive those who really need specialist care. Therefore, making the correct decision at the scene of injury would be of great help. Nonetheless, most of the times this does not occur and severely injured patients are transported to the closest emergency department of a non-trauma center [6]. Although in some rural areas undertriage and transport of severely injured patients to non-trauma centers are inevitable, in many other cases undertriage occurs since the necessity of trauma center care is not realized in the prehospital setting [6]. The uniqueness of each patient and the complexity of patient assessment in the scene of injury might lead to disregard occult injuries, such as abdominal injuries, that are challenging to detect [7, 8]. In the United States, for example, one-third of severely injured patients are admitted to non-trauma centers, while some others die in the emergency department or are transferred to a trauma center for adequate care [6].

Focusing on traffic safety, unlike active and passive safety systems, which have successfully been improved, prehospital care has not been treated in depth [3]. However, it has been demonstrated that early diagnosis and triage of patients is of great benefit to reduce medical risks [2, 9]. Prehospital care is often characterized by its continuously changing and unstable environment, which makes it so unique. Different types of patients, lack of adequate equipment and a lack of studies might lead to error when providing prehospital care [10]. Knowledge of the field, in shape of education, decision support, equipment improvement or many others should be used as a tool to considerably reduce the error probability occurrence and improve the quality of the prehospital care [10].

Triage protocol, considered as a decision support tool, enables severely injured patient identification. Therefore, an updated and highly accurate triage protocol is required. Defined as *"the sorting of patients into priority groups according to their needs and the resources available"* [11], triage takes into account different factors such as the type of injuries, available hospital services or means of transportation to ensure an efficient use of those resources. Although many countries (21 countries from the European Union (EU) Member States) have introduced triage protocols in their ambulance services, a standardized version is not yet available [11, 12].

In the United States (US), triage system based on the *Guidelines for Field Triage of Injured Patients - Recommendations of the National Expert Panel on Field Triage* is widely used by Emergency Medical Services (EMS) and trauma systems [8]. Divided into four steps (Figure 1.1), physiological criteria and anatomical criteria of identified injuries are assessed respectively. If any of those two steps is fulfilled, the patient is recommended to be transported to a trauma center. However, since injury might not always be that obvious, a patient who is not fitting previously mentioned criteria will be sorted in terms of Mechanisms Of Injury (MOI, step 3) or Accident Characteristics (AC). In this case, although the patient needs to be transported to a trauma center, the highest level of a trauma center may not be required. The last step would include those cases where although neither physiological, anatomical nor mechanisms steps have not been met, comorbid factors highly increase the risk of injury [8].

On the other side, Rapid Emergency Triage and Treatment System (RETTS) is considered the first option in Sweden for providing decision support when sorting patients in different degrees of severity [9]. Introduced in most emergency departments in the recent years, the protocol consists of five priority levels (blue, green, yellow, orange and red from lowest to highest (Figure 1.2)). The *blue* level is provided when no emergency care or hospital facility is needed. The rest of the levels are determined based on two steps that include an algorithm for vital signs and another algorithm for different chief complaints. As in the case of the triage system used in the US, the patient is given the highest priority level whenever any of the physiological or anatomical steps is fulfilled. However, in this triage system, if any MOI criteria are met, the orange level in RETTS is given [3, 9].

The exclusive use of physiological and anatomical criteria has been demonstrated to often lead to undertriage, strongly suggesting the use of MOI in triage systems [3]. However, the difficulty to effectively applying field triage guidelines in real circumstances, due to the complexity of the patient assessment in the field, often leads to prioritize personal intuition based on experience and available information [13]. Therefore, the usability of guidelines should be strongly taken into consideration in order to guarantee protocol adherence [13].

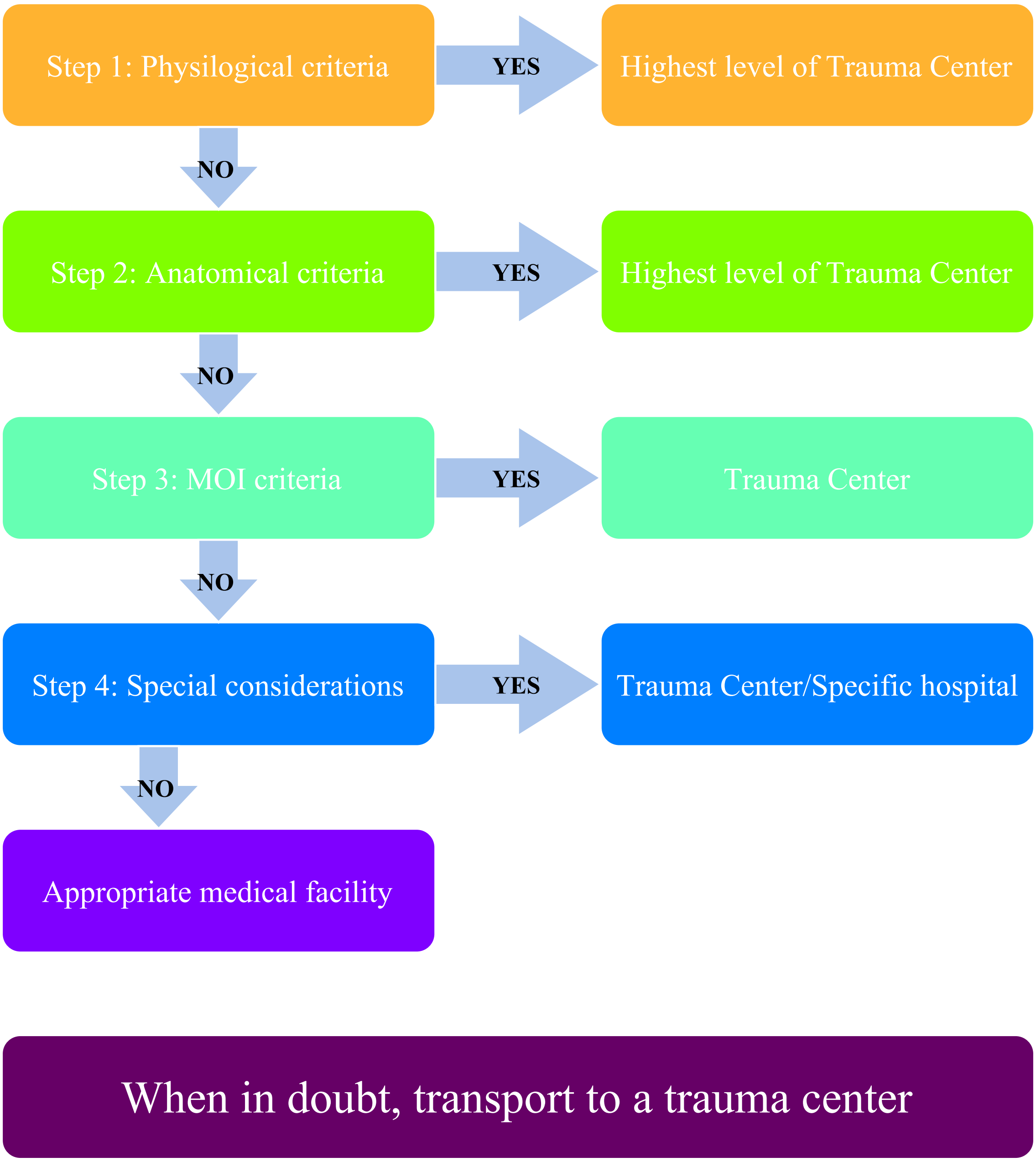


Figure 1.1: Field triage decision scheme (US) [8].

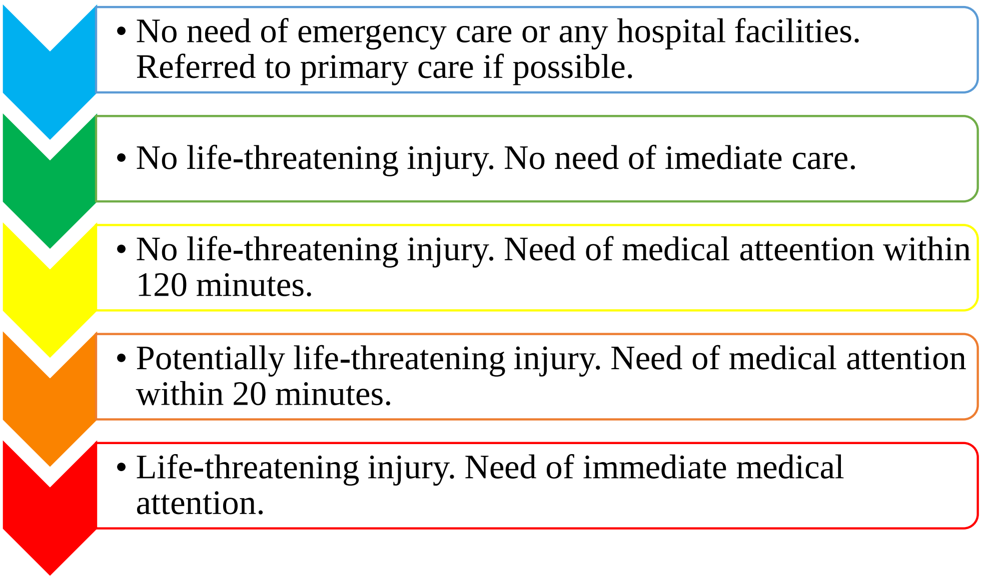


Figure 1.2: Field triage decision scheme (Sweden, RETTS) [9].

1.1 On Scene Injury Severity Prediction (OSISP) algorithm

Field triage difficulty has been addressed by a project within the frame of SAFER (Vehicle and Traffic Safety Center, Chalmers) by developing a new OSISP algorithm for car passengers involved in road crashes. The prior objective of Buendia, Candefjord et al., 2015, was to improve the current triage of casualties in Sweden and if possible, countries with similar traffic environments [3]. In order to do so, only easily assessable AC at the accident scene were used to determine the value of those for triage systems. As mentioned before, AC or MOI appear to be strongly supported for field triage due to their capacity to predict imperceptible injuries to the naked eye and therefore reduce undertriage.

The algorithm was defined as a good predictor for sorting severe and non-severe injured patients with an Area Under the Receiver Operator Characteristic (ROC) Curve (AUC) equal to 0.83 and 0.78 for Injury Severity Score (ISS) value set to higher than 15 and 8 respectively (Figure 1.3). In other words, the OSISP algorithm designed in this study may be used as a support of triage protocols such as RETTS in order to improve their accuracy.

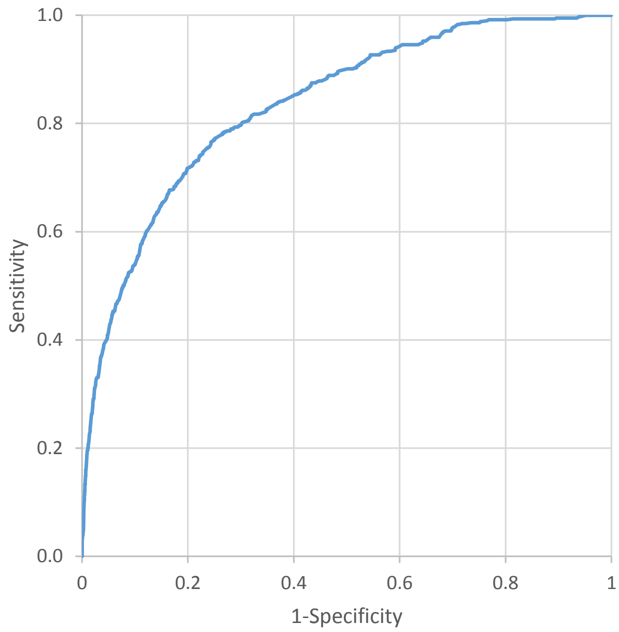


Figure 1.3: ROC curves for the full model with threshold ISS>15 [3].

1.2 Aim of the project

As it has been shown, the use of the OSISP algorithm in the prehospital stage has the potential to become a solution to improve the triage accuracy. For that reason, a pre-study to begin the process of implementation into clinical practice was initiated by the Prehospital ICT Arena (PICTA) at Lindholmen Science Park in Göteborg. The first step was a low fidelity prototype. The present thesis lay into the frame of PICTA and aims for an IT-solution for clinical evaluation of the OSISP algorithm.

The solution consists of a smartphone App that is designed to naturally fit into the normal workflow of an ambulance. The smartphone App is meant to be developed into a practical clinical evaluation solution. If the final solution is successfully evaluated in the clinical practice, the ambition is to integrate the algorithm in other ambulance ICT-platforms.

1.3 Background

Studies have been carried out in order to provide a better field triage system by using vehicle telemetry, which is recommended by the expert panel in field triage [14]. Indeed, its potential to more accurately guide trauma triage decisions has been pointed out. Advanced Automatic Collision Notification (AACN), a service which is already installed in millions of vehicles, is designed to automatically alert EMS about the occurrence of a car accident [14].

General Motor's OnStar unit, for example, is working on this new technology based on telemetry to predict the severity of crash casualties before the dispatch of EMS to the scene of accident. This would allow to predict the severity and priority of patients beforehand [15].

In addition, in [16], based on vehicle telemetry data, an algorithm for Injury Severity Prediction (ISP) that achieved a performance of 63.64% sensitivity and 96% specificity was proposed. However, the use of telemetry appears not to be always a good solution due to differences in the Sensing Diagnostic Module (SDM) system among different vehicles [16]. Besides, the use of telemetry systems is limited in Europe [3]. Therefore, an algorithm that predicts injury severity based on assessable AC in the scene of the crash, like [3], would be of great help.

2

Theory

2.1 Logistic regression modeling

In [3], (binary) logistic regression was used to classify severely and non-severely injured casualties of a car accident. This statistical method is often used to analyze datasets where the probability of a dichotomous dependent outcome is estimated based on independent explanatory variables [17]. In other words, the dependent variable is considered as binary and only accepts values 0 (false), in case of failure, or 1 (true) in case of success. As mentioned, the result of the outcome (Y) depends on a set of predictor variables $X(X_1,\ X_2,...,\ X_m)$ that contribute to the probability of success of the studied characteristic [17].

The aim of the logistic regression revolves around coming up with the best fitting model that relates the outcome with the set of independent features [17]. Therefore, how the presence of each of those variables affects in the probability of the resulted outcome can be analyzed to be able to predict the result of upcoming cases. This property has made of logistic regression a widely used tool in machine learning problems including medical aspects such as field triage in traffic road accident, which is the case of this study. The following variables can be then declared:

- $Y_i,$ (2.1)

a given binary outcome ($Y_i = 0$ or $Y_i = 1$) where i represents the observed example [18].

- $X^i = (X_1^i, X_2^i, ..., X_n^i),$ (2.2)

a set of independent continuous or discrete features [18].

- $h_\theta^i(X^i) = g(z) = g(\theta^T X^i) = \dfrac{1}{1 + e^{-(\theta^T X^i)}},$ (2.3)

where $z = \theta^T X^i = \theta_0 + \theta_1 X_1^i + \theta_2 X_2^i + ... + \theta_n X_n^i$ [18].

h_θ^i, known as hypothesis sigmoid/logistic function (Figure 2.1), tries to fit the data so that it becomes a good predictor for the corresponding value of Y (h:X→Y). In other words, the hypothesis function estimates the probability of success on a given input X parameterized by coefficient θ, ($h_\theta^i(X^i) = Pr(Y_i = 1|X_i = x_i; \theta)$). As it can be observed in Figure 2.1, $z = \theta^T X^i \geq 0$ means that $h_\theta^i \geq 0.5$ and therefore a positive prediction. On the other hand, $z = \theta^T X^i \leq 0$ results in $h_\theta^i \leq 0.5$, which corresponds to a negative prediction [18].

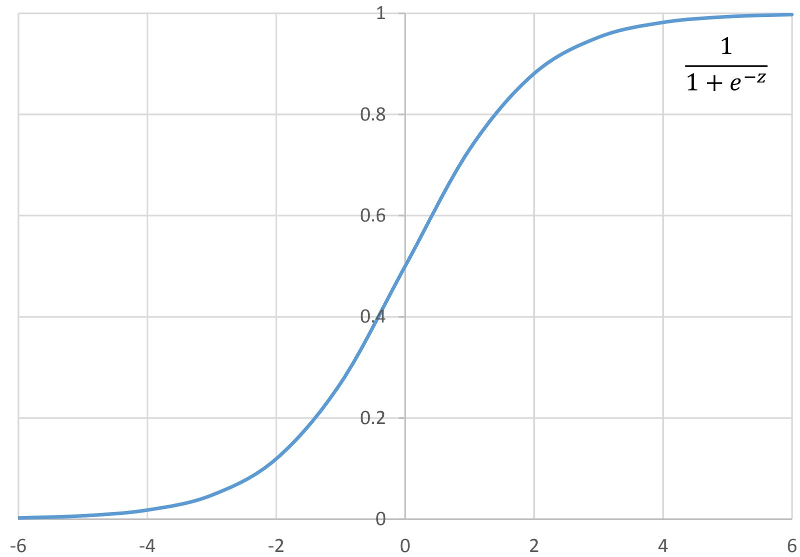


Figure 2.1: Sigmoid/Logistic function.

In order to do so, the logistic regression model looks for coefficients $\theta(\theta_1, \theta_2, ..., \theta_n)$ that predict the logit transformation (or logarithm of odds, which is the inverse of the sigmoid function) of the probability of success of the analyzed characteristic by a linear function of the explanatory variables [18]:

- $$it(P) = ln(\frac{P(Y=1|X=x;\theta)}{1-P(Y=1|X=x;\theta)}) = ln(\frac{(h_\theta(X)}{1-(h_\theta(X)}) = \theta_0 + \sum_{k=1}^{n} \theta_k X_k \quad (2.4)$$

2.2 Injury Severity Score (ISS)

Injury Severity Score is an anatomical scoring process that reduces complex and variable patient data in a single score that provides accurate information about the severity of patient's injuries [19]. Based on the Abbreviated Injury Scale (AIS), a score between 1 and 6 (being 1 minor and 6 not survivable) is given to each injury and is allocated according to the affected region (head, face, chest, abdomen, extremities, external) [19].

Then, the three body regions with the higher score or the three most severely injured regions are squared and added together resulting in the ISS score (0-75) [19]. As mentioned in [3], ISS$>$ 15 is mainly considered as an adequate threshold to dichotomize between severe and non-severe injury.

2.3 Assessment and Emergency Care

According to its intended purpose, the development of the OSISP App should strongly take into consideration patient assessment procedure in emergency situations and fit into paramedics' work-flow. Therefore, it seems reasonable to get some basic knowledge concerning assessment and emergency care.

Even if the way of proceeding might slightly vary depending on the country or the medical center, in most cases, clinical practice in prehospital care is divided in the primary and secondary survey before the delivery of the patient in the corresponding hospital (Figure 2.2) [20]. Obviously, those two should be carried out as soon as the accident scene is reached and simultaneously with care provision.

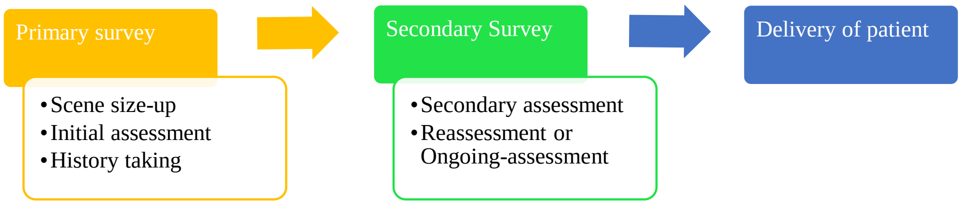


Figure 2.2: Assessment and Emergency Care.

2.3.1 Primary survey

2.3.1.1 Scene size-up

Every patient assessment should start with a scene size-up to ensure every member's safety as well as the scene safety. This process corresponds to the steps taken when paramedics reach the accident location. Scene management is carried out by taking standard precautions, such as wearing gloves or eye protection, determining the number of patients and identifying the necessary equipment to proceed. Observing the surroundings and looking for indicators may suggest the MOI and therefore the type of injuries and their severity [21, 22].

2.3.1.2 Initial assessment

Forming a general impression, based on patient's level of consciousness using AVPU (Alert, Verbal, Painful, Unresponsive) scale, might help to determine the priority of care. The objective of the initial assessment consists in detecting and responding to any possible threat to life [20]. In order to do so, it is essential to identify threats to the Airway, Breathing and Circulation (ABC). After a cervical spinal stabilization (in case spinal injury is suspected), an opened and clear airway, as well as a correct and periodic breathing, are ensured [20]. In the same trend, patient's cardiovascular status is established by evaluating the pulse, the temperature or the skin color [20].

According to the initial assessment, the type of patient must be determined to set a priority among them and therefore, the destination of the transport decided. Notice that this process could vary in case of infants or children [20].

2.3.1.3 History-taking

Once life threats have been identified and treated, MOI can be reconsidered in order to determine the chief complaint of the patient using *OPQRST* questions (standing for Onset of the event, Provocation/Palliation, Quality of the pain, Region, Severity, Time) and gather a *SAMPLE* history (standing for Signs/Symptoms, Allergies, Medication, Past medical history, last oral intake, Events leading to the illness or injury) [21].

Indeed, history-taking appears to be a diagnostic tool for chief complaint in the field. *OPQRST* is a learning technique commonly used in the medical field that consists in discerning the cause of the symptoms [21]. *SAMPLE* is also a mnemonic acronym often used in the EMS to refer to key questions that might help to figure out a history [21]. Notice that in some cases, past known medical problems that could be related might be of great help. In addition, bystanders or family may be used to make the history more consistent or even feasible in case the patient is unresponsive [21].

2.3.2 Secondary survey

2.3.2.1 Secondary assessment

In this step, a more in-depth physical examination is carried out. According to the literature there can be two type of physical examinations: full body or focused examination [21].

In the first case, also known as the head to toe physical examination, a quick examination is enabled to identify hidden or potentially life-threatening injuries. This type of assessment is usually performed in most critical patients who might be unconscious, confused or unable to specify their main complaint [21]. On the other hand, if an isolated injury is suspected a focused examination is carried out on the injury or chief complaint area [22]. This type of examination is often performed on stable patients. At this point, patient's vital signs are checked every five minutes to observe any shift or anomaly in their trend [21, 20].

2.3.2.2 Reassessment or Ongoing assessment

This assessment is continuously conducted in all patients on their way to the hospital [22]. Vital signs, ABC threats, mental status or physical examination are constantly re-examined [21]. It enables to reevaluate previous assessment and check effectiveness of provided treatment and interventions in the patient state.

The communication and documentation are considered as important as the assessment part [21]. Indeed, exhaustive information concerning the crash scene, the MOI, patient's status, provided assessment, as well as relevant observations, must be documented and described in proper medical terminology to the medical receiving hospital and trauma team [21].

3

Material and Methods

3.1 Development Requirements

Since the IT-solution was designed for field evaluation, the OSISP App had to be designed so as to be used at any stage of prehospital care. The necessary information would be provided by the user by a very intuitive process where different data, such as the scene safety, patient and call ID and AC options had to be filled. Then, the OSISP App would ask about an obvious assessment of injury severity that would be compared to the result provided by the OSISP algorithm. This would allow to determine how useful the implementation of the designed model would be.

Once, all the information is provided, the user would have the option to upload the recorded data to the cloud by using a SIM card or connecting to a WiFi if working off-line. The data would be stored in a server with a suitable format and structure that would be accessed and analyzed for each road crash. The standard followed for information storage and access was determined through a literature review. A fundamental part of the analysis was the result of the crash what meant the medical outcome of the patient, e.g. from the hospital. Therefore, the casualty would be identified and contacted to ask for participation and informed consent.

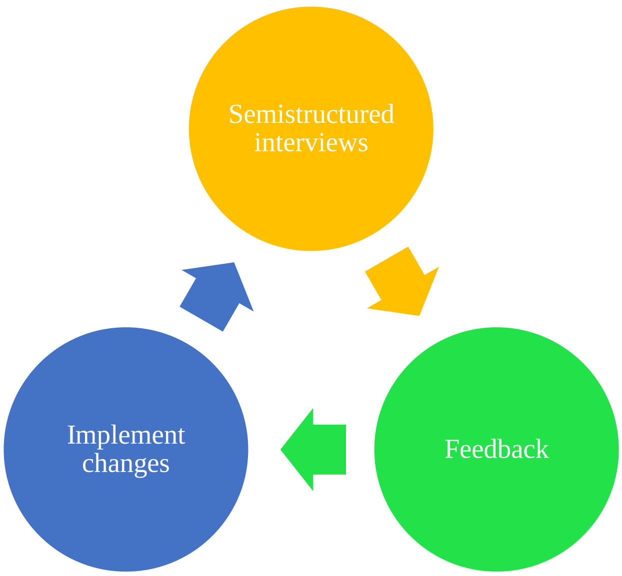


Figure 3.1: Software development cyclic process.

The development will follow a typical software development cyclic process (Figure 3.1). Feedback was obtained through semistructured interviews and suitable testing, such as simulation environments.

3.2 Android based application

The OSISP App was developed to be used in a smartphone based on Android operating system and available to be downloaded in Google Play. Notice that Android was chosen since according to [23] around 66% of the mobile/tablet operating system market currently corresponds to Android. Therefore, in order to create the OSISP App, it was necessary to get familiar with the mobile operating system and its software development.

Indeed, applications for Android are based on Java programming language and the Android software development kit (SDK), where different tools such debuggers or libraries are available [24]. Even if Android Studio, which was used for this project, is the official Integrated Development Environment (IDE), App developers are allowed to use others.

Notice that in order to run the OSISP App, Android Studio provides the option to do it in an emulator or on a real device. The use of a real device (Nexus 4) was considered to facilitate the cyclic software development and testing process.

3.3 OSISP algorithm

The OSISP algorithm based on logistic regression modeling designed in [3] was used and implemented in the OSISP App for severely and non-severely injured casualties classification. The development of the model was based on available data in the Swedish Traffic Accident Data Acquisition (STRADA) database between 2003-2013. STRADA is the Swedish Transport Administrations national information system, that keeps track of traffic accidents occurring on the Swedish road network. The algorithm was developed by setting AC which were feasible to assess at the scene of the accident and believed to be valuable predictors of severe injury. Variables included in the model are detailed in Table 3.1.

Variable	Definition/Source	Level/frequency	Description
ISS	Injury severity Score	ISS≤8 (95.1%) 8<ISS<15 (2.9%) ISS>15 (2.0%)	Whether the occupant is severely injured or not
Belt Use	Belt use	Belted (94%) Unbelted (5.9%)	Whether the occupant used seat belt or not
Airbag	Airbag deployment	Not deployed (59.6%) Deployed (38.3%) No airbag (2.1%)	Whether the airbag (if present) was deployed or not
Type	Type of accident	Single (31%) Intersection (22.8%) Longitudinal (12.7%) Rear end (27%) Tram/train (0.2%) Wild life animal (3.2%) Other (3.1%)	Collision with stationary object/departure from the road Collision with another (head on or side) vehicle in an intersection Collision with another (head on or side) vehicle outside an intersection Impact with another vehicle from behind Collision with tram/train Collision with a wild life animal (WLA) Other type of accident
PSL	Posted speed limit	20 km/h (0.01%) 30 km/h (1.2%) 40 km/h (0.8%) 50 km/h (29.1%) 60 km/h (1%) 70 km/h (31%) 80 km/h (4.3%) 90 km/h (20.1%) 100 km/h (2.9%) 110 km/h (8.8%) 120 km/h (0.7%)	Maximum speed allowed where the accident occurred
Location	Location of the accident	Urban (37.6%) Rural (62.4%)	Whether accident occur in urban or rural environment
Position	Seat position	Front (94.5%) Back (4.5%)	Seat position of the injured occupant
Elderly	Victim over or under 55 years old	≤55 (78.4%) ≥55 (21.6%)	Age 55 years used as threshold
Sex	Sex of occupant	Male (53.6%) Female (46.4%)	Male or female occupant
Period	Calendar years	2003-2006 (18.8%) 2007-2013 (81.2%)	In 2007 the injury coding system was changed

Table 3.1: Definitions and descriptions of the model variables. For each variable level the proportion (frequency) of the casualties having that characteristic is shown [3].

In this project, the threshold between severely and non-severely injured patients was established at ISS>15 since, as mentioned before, according to the US National Expert panel, this is the recommended way to dichotomize between both cases [3]. Table 3.2 shows the results obtained by the developed model.

As mentioned in Section 1.2, Buendia and associates' findings demonstrated that the OSISP algorithm appeared to be a good predictor of severely injured casualties. According to their results (Table 3.2), the use of the belt, the type and environment of the accident, the age of the car occupant and the posted speed limit were important predictors and variables to be taken into consideration due to their statistical significance. However, the airbag deployment, the occupant's gender and the seat position showed a weak association with injury severity.

Variable	β	OR (e^{β}) [95% CI]
Belted/unbelted	-2.1	0.13 [0.1, 0.16]
Airbag (not deployed)		
Deployed	0.10	1.10 [0.91, 1,3]
No airbag	0.34	1.4 [0.82, 2.4]
Type (rear end)		
Intersection	1.2	3.4 [2.2, 5.5]
Longitudinal	2.7	15 [9.5, 23]
Other	1.5	4.4 [2.4, 8.4]
Single	1.6	5.1 [3.3, 7.9]
Tram/train	2.3	9.7 [1.3, 75]
WLA	1.3	3.8 [2.0, 7.1]
PSL (30 km/h)		
20 km/h	-16	0 [0, -]
40 km/h	1.1	2.9 [0.4, 21]
50 km/h	0.60	1.8 [0.44, 7.6]
60 km/h	0.87	2.4 [0.38, 15]
70 km/h	1.0	2.7 [0.66, 11]
80 km/h	1.2	3.5 [0.8, 15]
90 km/h	1.5	4.4 [1.1, 18]
100 km/h	0.85	2.3 [0.49, 11]
110 km/h	0.40	1.5 [0.34, 6.5]
120 km/h	0.86	2.4 [0.32, 17]
Rural/urban	0.58	1.8 [1.4, 2.3]
Back/front	0.25	1.3 [0.9, 1.8]
>55/≤55	0.92	2.5 [2.1, 3.0]
Female/male	0.33	1.4 [1.2, 1.7]
2007-2013/2003-2007	-0.87	0.42 [0.35, 0.51]
Constant	-5.1	0.006

Table 3.2: Results for the multivariate analysis for ISS$\geq$ 15. The variable level used as reference is shown as the last level given (for predictors with two levels) or within parenthesis (for predictors with more than two levels) [3].

In the case of the seat position, to sit in the front seems to be slightly safer probably due to a higher appropriate use of the belt in such a position rather than in the back. However, as said, no significant association was found between this variable and ISS. Therefore, it was decided to dismiss seat position as a potential AC to predict severe injuries and has not been included in the OSISP App. In order to be able to run the algorithm, its value was fixed to the most probable case, which according to Table 3.1 is the front seat (94,5%). In order to develop the model, the period of time was also considered. However, there was no way of registering new cases in any of these periods. The variable regarding the period of time when the accident occurred was also fixed to the most probable case (2007-2013 (81.2%)). In addition, it was assumed that the later time period had a greater similarity with today's traffic environment.

On the other hand, the weak relation between the airbag deployment could be caused by the fact that accidents, where the airbag is deployed, tend to be more violent. Furthermore, airbag deployment is included in RETTS as triage criteria. Therefore, it has been decided to include airbag deployment in the OSISP App despite its weak association according to the logistic regression model. In the case of missing values in any of the variables, the value of the most probable case according to Table 3.1 would be set.

In order to run the OSISP algorithm, it is necessary to determine a probability threshold that differentiates severe and non-severe injured casualties. In other words, it is necessary to choose a cutoff value in the curve obtained in Figure 1.3 that corresponds to a related specificity and sensitivity and determines the overtriage and undertriage levels (3.3). Therefore, the cutoff value (p=0.0082) corresponding to 90% and 50% of sensitivity has been defined as a threshold, i.e. probability of being severely injured equal or greater to that value would be considered as severely injured patients.

Table 3.3: Contingency table/Confusion matrix.

	Disease Positive	Disease Negative
Positive prediction	**True Positives (TP)**	**False Positives (FP)**
Negative prediction	**False negatives (FN)**	**True Negatives (TN)**

- $Sensitivity = TP/(TP + FN)$ (3.1)
- $Specificity = TN/(TN + FP)$ (3.2)
- $Undertriage = 1 - Sensitivity = FN/(TP + FN)$ (3.3)
- $Overtriage = 1 - Specificity = FP/(TN + FP)$ (3.4)

3.4 Data Storage

The data had to be stored in a server in order to make it accessible for the researcher to test the validity of the designed model. The cloud-based server available for *"Jalp!"*, an Android based App developed by students from Chalmers University of Technology [25], was used to store and upload the data in this thesis.

Apache Commons Net library was included so as to provide the OSISP App the functionality to store the relevant data in the remote server. Precisely, this library contains the *FTP Client* Java class that allows interaction and file transfer through the standard network protocol File Transfer Protocol (FTP) [26].

However, in order for the researcher to remotely access the uploaded data to the server, the open source software FileZilla Client was used. Based on FTP, Filezilla is considered one of the most reliable and updated FTP client. As Apache Commons Net library, this software also enables the transfer of computer files between the server and the user/client [27].

3.5 Data Structure

Data acquisition needs a structure that allows information to be efficiently transmitted and accessed by hospital members. Therefore, JavaScript Object Notation (JSON) lightweight format was considered. Commonly used for exchanging data in Web applications, JSON documents are characterized by its simplicity to be read and written both by humans and machines [28, 29]. Represented as an object (surrounded by {}) or an array (surrounded by [ ]) structure, JSON documents consists of "key":"value" pairs [30]. As [28] mentions, notation structure can vary from system to system but always fulfill two principles:

- If J is a JSON object, then one should be able to access the JSON value in a specific "key":"value" pair of this object.

- If J is a JSON array, then one should be able to access the i-th element of J.

According to this, each casualty is considered an object with a "key":"value" pair "Patient Information":"Array of valuable variables". The array contains AC (Table 3.1) and some other valuable information and has the following structure:
Patient ID: ""
Call ID: ""
Age: *"Below 55" or "Above 55"*
Gender: *"Male" or "Female"*
Airbag deployment: *"Airbag deployed" or "Airbag not deployed"*
Belt use: *"Belted" or "Not Belted"*
Environment: *"Rural" or "Urban"*
Type of Accident: *"Single" or "Intersection" or "Longitudinal" or "Rear end" or "Tram/Train" or "Wild Life" or "Other Type"*
Posted Speed Limit: *"20 km/h" or "30 km/h" or "40 km/h" or "50 km/h" or "60 km/h"or "70 km/h" or "80 km/h" or "90 km/h" or "100 km/h" or "110 km/h" or "120 km/h"*
Personal judgement: *"Severely injured" or "Not Severely injured" or "Nothing Obvious"*
GPS location: ""
Location: *"At Scene Place" or "Not at Scene Place"*
Date and Time: ""
Probability of being injured: ""
Clinical decision: *"TRAUMA CENTER" or "NOT TRAUMA CENTER"*

Objects or casualties belonging to the same car accident are in turn saved in an another array. Data is represented with the following structure:

Casualties of the accident $= [\{\textit{“Patient Information”} : [\textit{Array with valuable variables}]\},$
$\{\textit{“Patient Information”} : [\textit{Array with valuable variables}]\},$
$\{\textit{“Patient Information”} : [\textit{Array with valuable variables}]\}, ...]$

3.6 Cyclic software development: Use of Semi-structured Interviews

Semi-structured interviews were carried out to people working in the prehospital field so as to get essential information for the design of the OSISP App. Their experience and feedback were of great help in the cyclic software development. Questionnaires were prepared beforehand, leaving the option of coming up with new questions or topics during the interview (Appendix A.1).

3.6.1 First Interview: Robert Höglind

A first semi-structured interview was performed in order to clarify initial doubts related to usual workflow and conditions of the paramedics. Some feedback from the first draft of the OSISP App was also requested. The interviewee was Robert Höglind, a former ambulance nurse with over 15 years of experience in the ambulance. He currently works as a quality developer at an ambulance and prehospital emergency care in Göteborg.

3.6.2 Second Interview: Bengt Arne Sjöqvist

According to gathered information, an advanced draft of the OSISP App was designed. In order to improve its performance and come up with possible weak points, Bengt Arne Sjöqvist was interviewed. Researcher and professor of practice in the Biomedical signals and systems research group at the Chalmers University of Technology, Bengt-Arne Sjöqvist was an eHealth pioneer developing systems solutions in prehospital and out of hospital care.

3.6.3 Third Interview: Magnus Andersson Hagiwara

Since the OSISP App is designed to be used by an ambulance crew, users' opinion was vital to guarantee the usability and reliability of the App. Therefore, Magnus Andersson Hagiwara was interviewed. After having worked as an ambulance nurse during 15 years, he is currently working as a doctor and researcher in prehospital care in Prehospen research center at the University of Borås.

3.6.4 Fourth Interview: Hans Törnqvist

In order to support previous information, Hans Törnqvist was also interviewed. Focused on ambulance training improvement in the region of Skaraborg, he works as an ambulance nurse since 2001.

3.7 Use cases

To validate and place value on obtained results it was necessary to prove effectiveness in different practical cases where the use of the OSISP App might be challenging. The objective of this process was to determine if the OSISP App was ready to face real life situations. Therefore three varied cases with different environment conditions were raised to ensure data privacy and performance reliability. No personal judgment is made in any of the use cases since no assumption or guess can be done regarding their way to proceed in such real case.

3.7.1 Use Case 1

Figure 3.2: Use Case 1 overview. The level of all variables included in the model are represented. Extra valuable information for the researcher (network availability, current location, patient identification and personal judgment regarding patient's injury severity (thumb down for severe injury, thumb up for non-severe injury, thumb horizontal for no assumption)) are also displayed.

A 26 years old man crashed his car into the back of a school bus when it stopped in a light traffic light (rear-end accident). The man was driving too close to the bus which made him unable to see the red traffic light. Fortunately, the car driver was using his belt. However, the airbag was not deployed. The bus was empty at that moment except for the bus driver who comes out unharmed from the accident. However, the car driver requires medical care. There are no more casualties in the crash scene.

The posted limit in this urban area is 50 km/h. Due to coordination of the EMS team, it is possible to run the OSISP App in the accident scene. Both Patient Id and Call Id have been provided.

3.7.2 Use Case 2

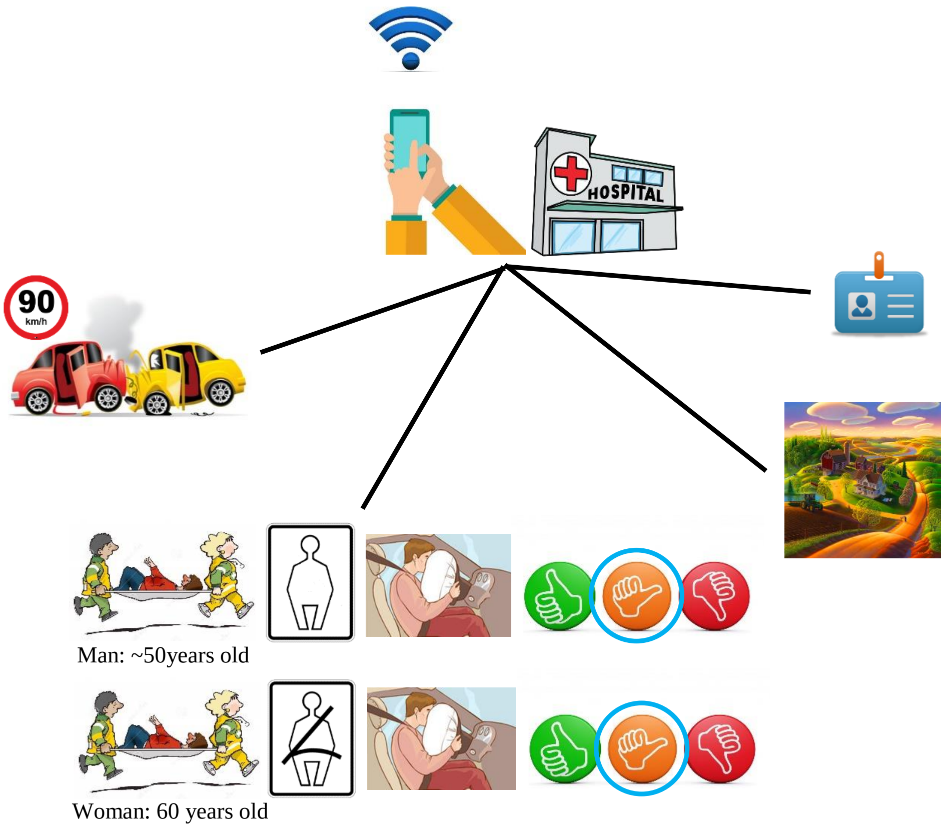


Figure 3.3: Use Case 2 overview. The level of all variables included in the model are represented. Variables that differ among different patients are displayed separately. Extra valuable information for the researcher (network availability, current location, patient identification and personal judgment regarding patient's injury severity (thumb down for severe injury, thumb up for non-severe injury, thumb horizontal for no assumption)) are also displayed.

Two cars are involved in a longitudinal (collision, head on or side, with another vehicle outside an intersection) accident on the outskirts of the city. In one car, a man is unconscious and does not carry any documentation that allows to identify him. However, even if his age can not have been determined, a range between 50-60 years old is suspected. He was not using the belt at the moment of the accident but the airbag deployment has slightly cushioned the impact. In the other car, a 60 years old woman who was using the belt and whose airbag was deployed appears to be conscious.

The posted speed limit in the accident scene is 90 km/h. Due to circumstances, the OSISP App is run after transporting the patients to the hospital. Both Patient Id and Call Id have been provided.

3.7.3 Use Case 3

Figure 3.4: Use Case 3 overview. The level of all variables included in the model are represented. Variables that differ among different patients are displayed separately. Extra valuable information for the researcher (network availability, current location, patient identification and personal judgment regarding patient's injury severity (thumb down for severe injury, thumb up for non-severe injury, thumb horizontal for no assumption)) are also displayed.

A multitudinous accident, where four cars are involved, has taken place in the highway 30 km away from the nearest hospital. The main responsible for the accident, who has borne the brunt, appears to be a man who is unconscious. His exact age can not have been determined but seems to be around 50-60 years old. The car that follows and has impacted on his attempt to avoid him was driven by a woman who is unconscious. She is accompanied by his boyfriend who is sitting in the codriver's seat He was not using the belt and is unconscious. They are trapped in the car when the EMS arrived to the scene of the accident. They are both 28 years old. The two other cars are driven by a man and woman who are 52 and 36 years old respectively. In these case both drivers are conscious.

All airbags were deployed and except for the 30 years old man from the second car, all casualties were using their belt in the moment of the accident. The posted speed limit in the crash scene is 100 km/h. Even if the EMS act as quick as possible in order to transport all patients to the hospital, there is time to run the OSISP App in the accident scene. However, there is no Internet connection till a while after. Furthermore, neither Patient Id nor Call Id has been provided.

4

Results

4.1 Design and performance of the App

The OSISP App is divided into seven main screens represented in Figure 4.1, which describes their role in the performance of the App. Each screen is described in detail in the following sections.

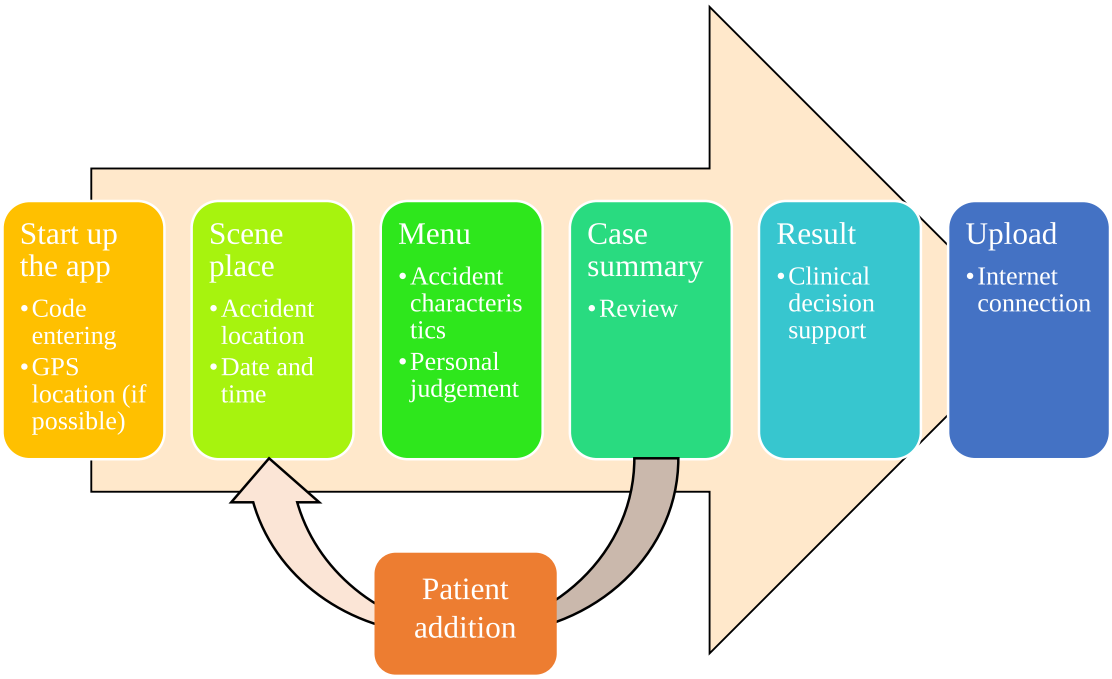
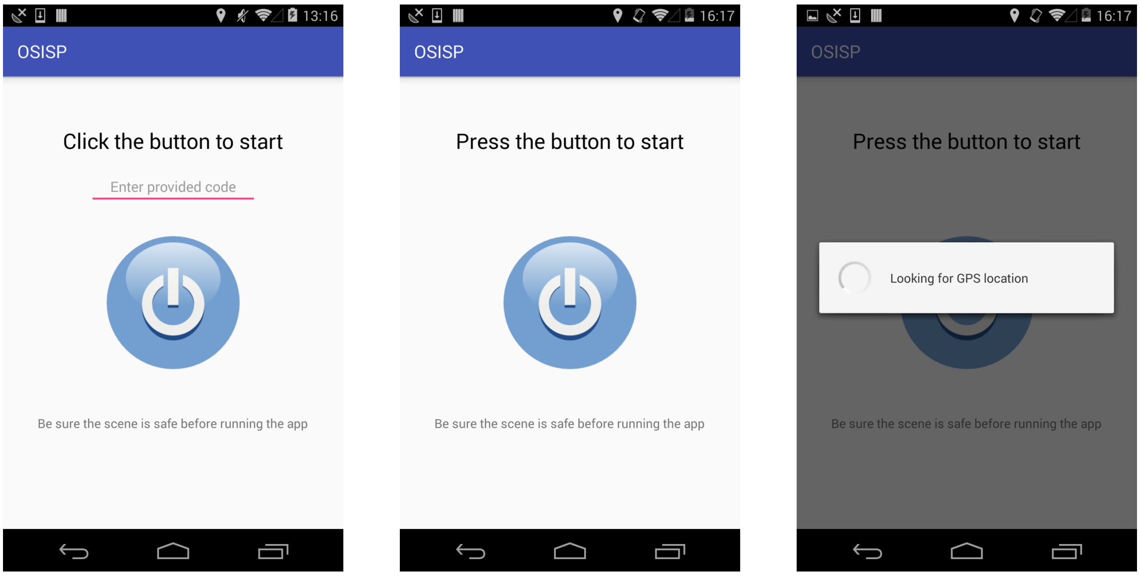


Figure 4.1: Overview of the App design and performance.

4.1.1 Screen 1: Start up the App



(a) In order to start the app the first time a determined code has to be entered.

(b) An overview of the design.

(c) GPS location is requested.

Figure 4.2: Screen 1: Start up the App.

The aim of the App is to perform a clinical study to evaluate the OSISP algorithm. Therefore, in order to avoid possible undesired users to upload irrelevant information, a code, which is provided by the researcher, is necessary to start the App the first time (Figure 4.2a). If the code is correct, the App will not require the user to provide it again in future occasions.

The design of the first screen is presented in Figure 4.2b. It consists of a *Start button*, placed in the middle of the screen, the hint *Click the button to start* for the user to start the process, and the reminder *Be sure the scene is safe before running the app* to avoid possible risk events while running the App.

If a network is available when the first screen is created, GPS location is requested (Figure 4.2c). GPS location might help to exactly locate the scene of the accident and identify the patients. Furthermore, if the evaluation of the algorithm is successful and is implemented in an ambulance software, GPS location could keep track of closest trauma centers if necessary. In case a network is not available when starting the app, this step is skipped.

4.1.2 Screen 2: Location

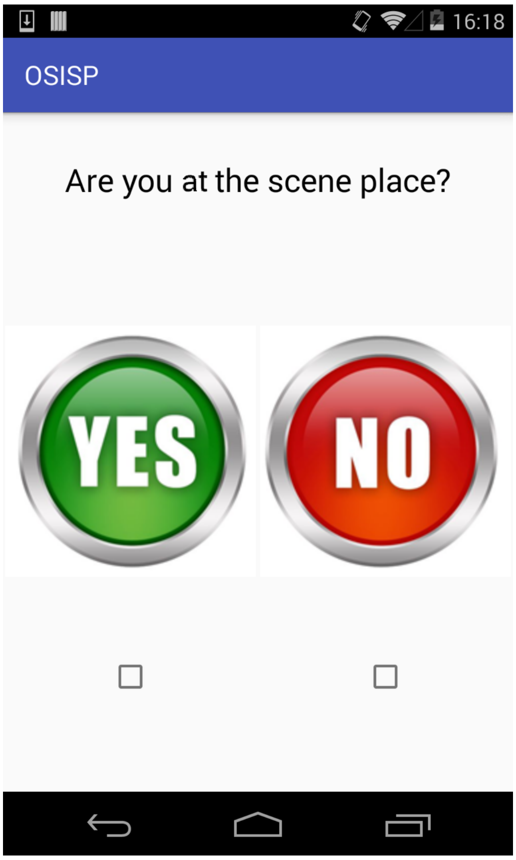


Figure 4.3: Screen 2: Location. An overview of the design.

In the second screen (Figure 4.3), the user location when using the App is requested. The question *Are you at the scene place?* is raised. Only two possible answers are suggested, *Yes* or *No*. Notice that the question has to be answered in order to move forward. This information gives feedback to the researcher regarding the availability of the user to run the App in the accident scene. In addition, the usability of the GPS location gathered in the first screen is highlighted. Date and time are also recorded in order to distinguish both patients and accidents for future analyses.

4.1.3 Screen 3: Menu/Accident Characteristics

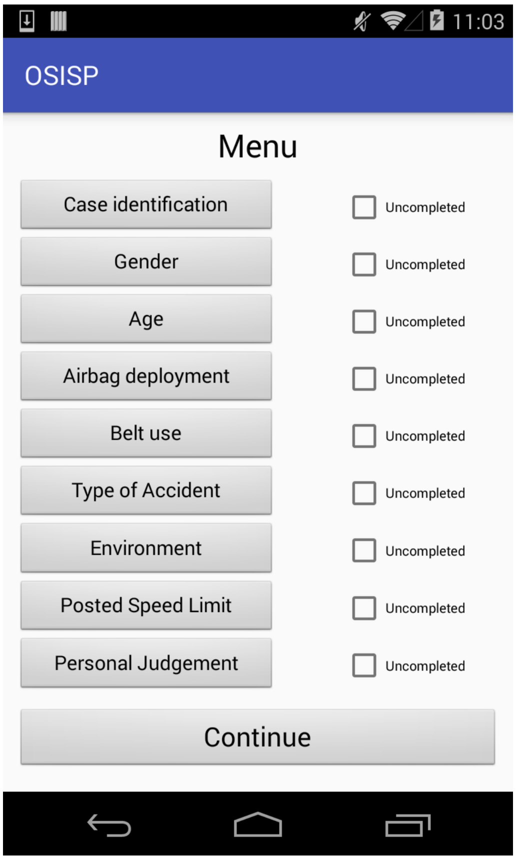
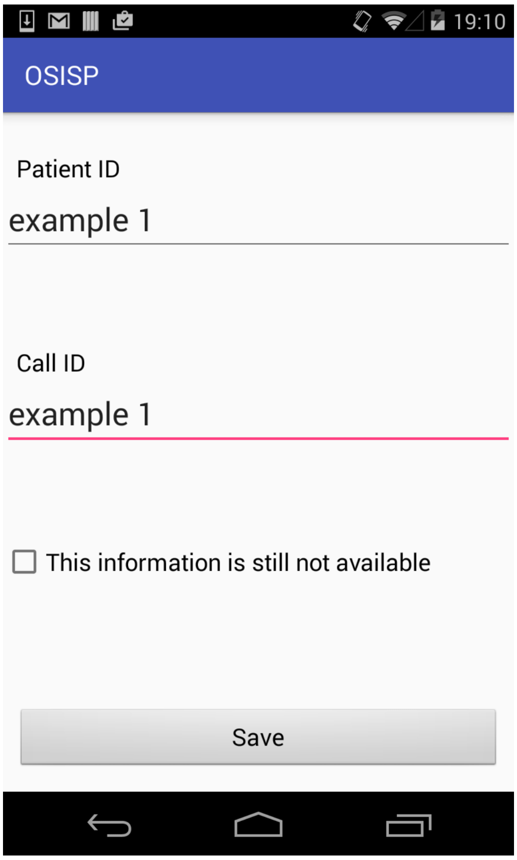


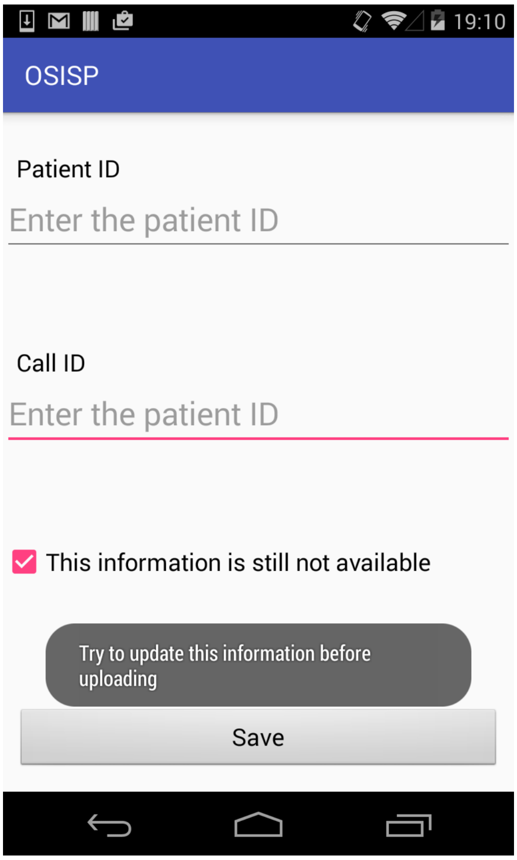
Figure 4.4: Screen 3: Menu/Accident Characteristics. an overview of the design.

Necessary AC for the OSISP algorithm to calculate the risk of injury, e.g. age, gender, airbag deployment, belt use, environment, type of accident and posted speed limit, as well as some other valuable information, e.g. case identification and personal judgment, are organized in a menu (Figure 4.4). If information has not yet been provided a checkbox with *Uncompleted* statement can be observed. This is replaced by the chosen level for each variable as soon as they are completed (see Figure 4.7a, 4.8a).

Based on the feedback of Bengt Arne Sjöqvist's interview, when an AC value is registered a time stamp is attached. Only the last modification is considered. Whenever the user has provided all the information that can assess and feels ready to move forward, the button *Continue* has to be clicked.



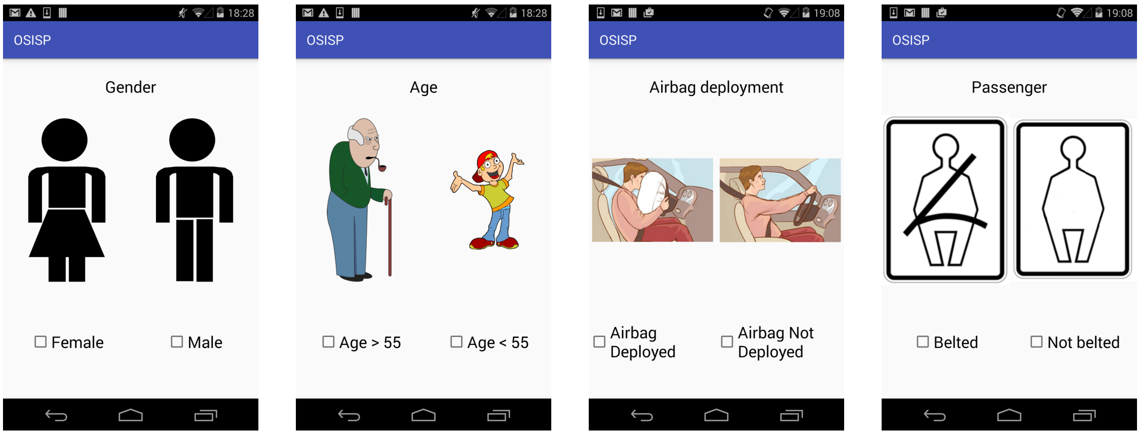
(a) Identification is available.



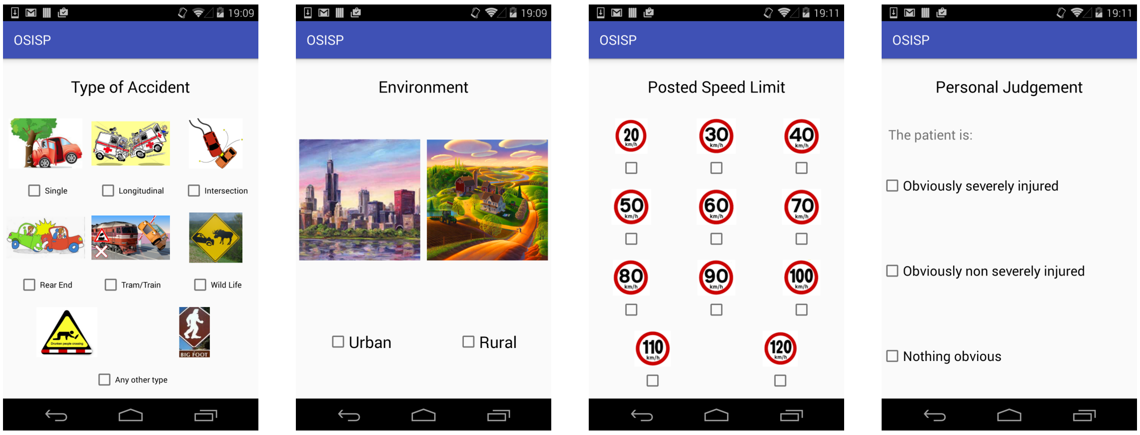
(b) Identification is not available.

Figure 4.5: Case identification.

In order to identify each patient, in Figure 4.5, *Patient Id* and *Call Id* are requested. An identification number is given to every accident and patient where an ambulance is involved (Figure 4.5a). However, this information might not always be available when the App is run. Therefore, the option *This information is still not available* is provided (Figure 4.5b). In this case, a so-called *Toast* notification is showed with the following message, *Try to update this information before uploading*. Whatever the situation, the button *Save* allows saving the data.



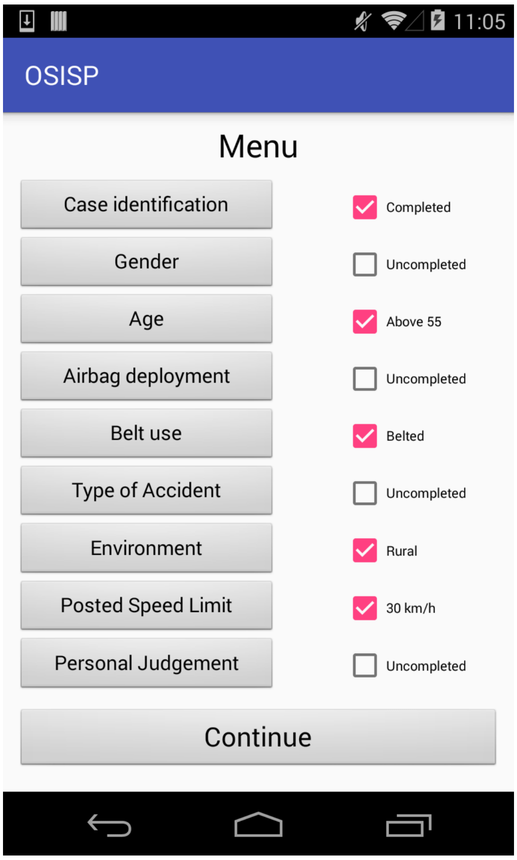
(a) Gender. **(b)** Age. **(c)** Airbag deployment. **(d)** Use of belt.



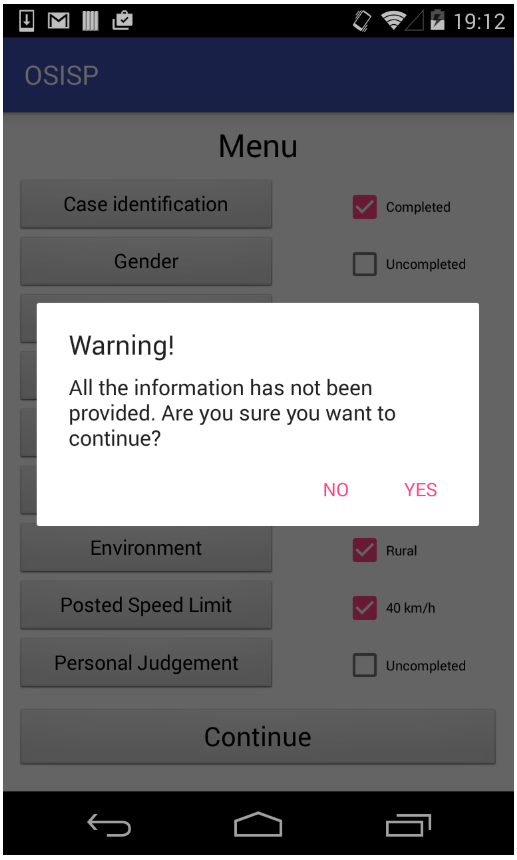
(e) Type of accident. **(f)** Environment. **(g)** Posted speed limit. **(h)** Personal judgement.

Figure 4.6: Accident characteristics and personal judgment.

The rest of AC, as well as the user personal judgment regarding the severity of the injured patient, are shown in Figure 4.6. Possible levels for each of the AC have been discussed in Section 3.5.



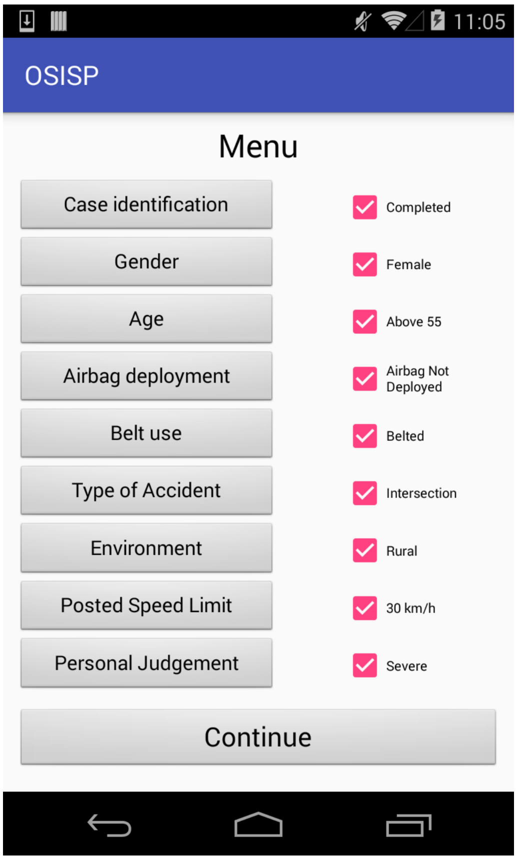
(a) A uncompleted menu.



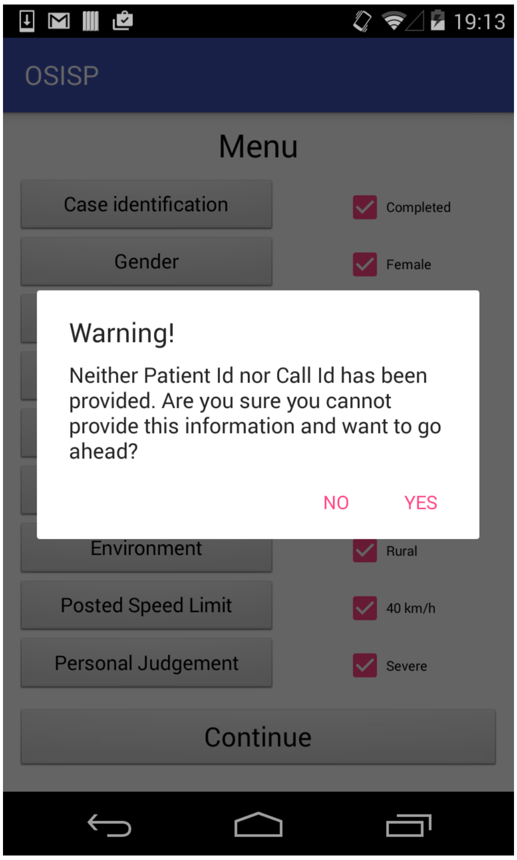
(b) A warning alert dialog is displayed if the menu is uncompleted.

Figure 4.7: Continuing is requested with an uncompleted menu.

Some of the AC might be unknown or unfeasible to assess (Figure 4.7a). In such a case, if the button *"Continue"* is clicked, a warning alert dialog is shown with the following message, *All the information has not been provided. Are you sure you want to continue?* (Figure 4.7b. Due to the importance of gathering all values to calculate the risk of severe injury, the alert dialog pretends to guarantee that the user is not able to assess any other AC and is willing to move forward.



(a) A completed menu.

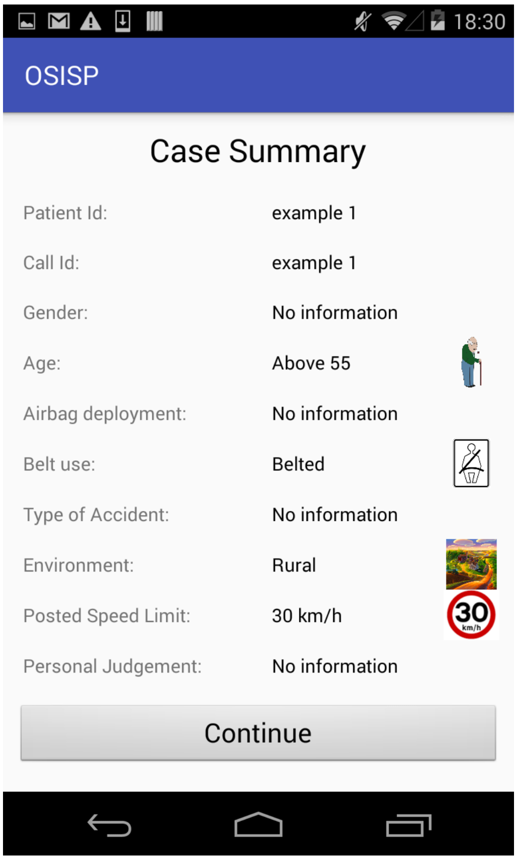


(b) A warning alert dialog is displayed if neither Patient Id nor Call Id is provided

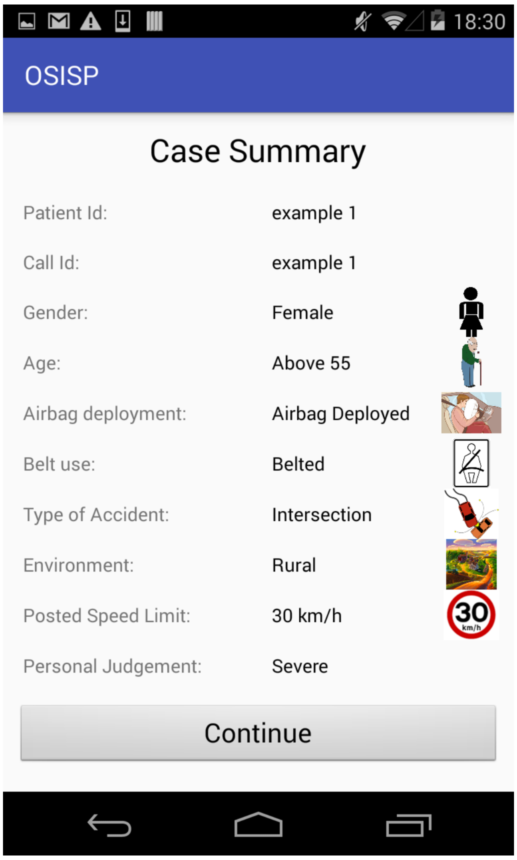
Figure 4.8: Continuing is requested with neither Patient Id nor Call Id.

Figure 4.8a shows a fully completed menu. However, if no identification has been given to *Patient Id* or *Call Id*, a warning alert dialog is shown with the following message, *Neither Patient Id nor Call Id has been provided. Are you sure you cannot provide this information and want to go ahead?*. Due to the importance of any identification number to identify each patient, the alert dialog pretends to remind the user how helpful this information can be.

4.1.4 Screen 4: Summary



(a) An uncompleted case summary menu.



(b) A completed case summary menu.

Figure 4.9: Screen 4: Summary. An overview of the design.

The objective of the case summary is to review that provided information is correct (Figure 4.9). Each variable with the corresponding chosen level is displayed. A small picture is also introduced to make possible errors more visual and easier to detect. If a variable is not provided (Figure 4.9a), *No information* is shown instead and no picture is displayed. Figure 4.9b simulates a fully completed case summary. The button *Continue* is clicked when information has been reviewed.

4.1.5 Screen 5: Add more casualties

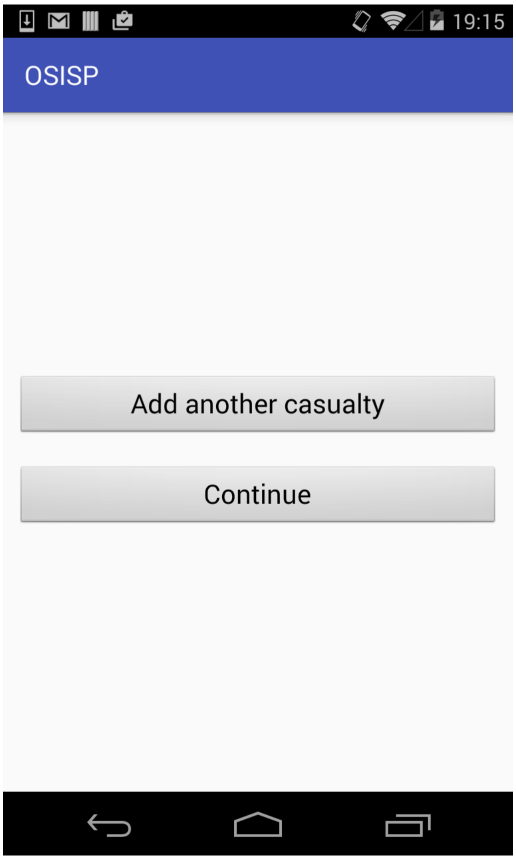


Figure 4.10: Screen 5: Add more casualties. An overview of the design.

Based on input from interviews, a possibility to triage several patients at the same time has been implemented (Figure 4.10). If the user wishes to add another patient, the button *Add another casualty* is clicked. As Figure 4.1 presents, information for the new patient has to be provided and Screen 2 (Section 4.1.2) will pop up again. When information of all patients has been registered the button *Continue* is clicked.

4.1.6 Screen 6: Recommended destination

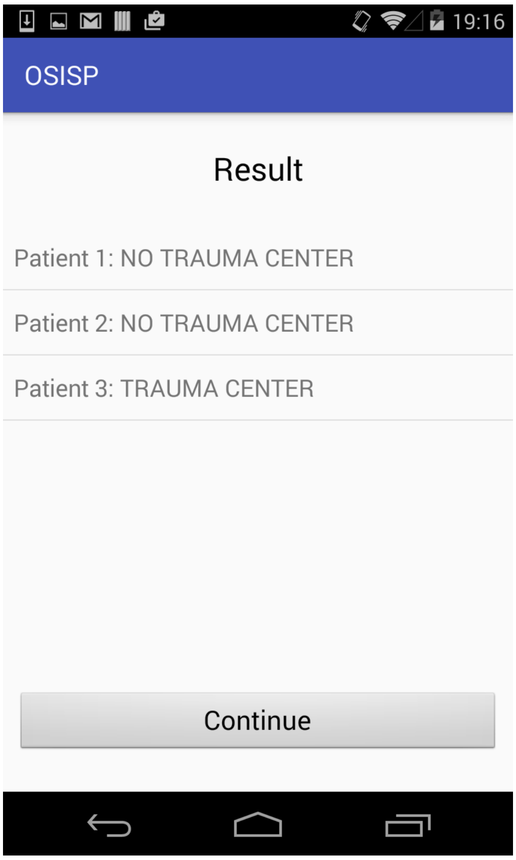
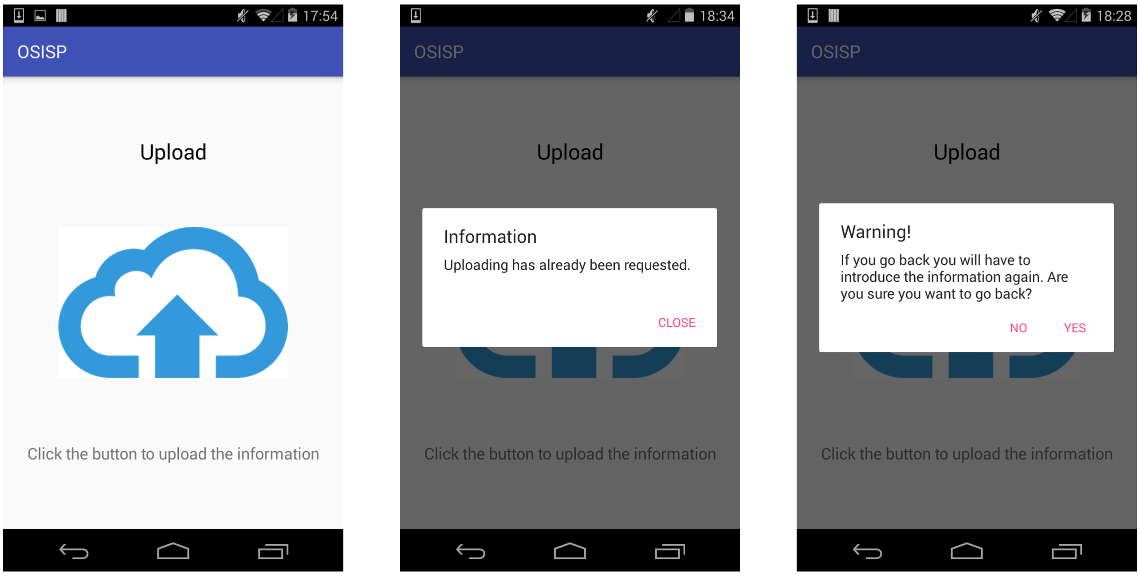


Figure 4.11: An overview of the design. The recommended destination is showed in a list.

Due to the future intended purpose of the algorithm as a computerized clinical decision support system, the App displays *TRAUMA CENTER* or *NO TRAUMA CENTER* for each patient depending on the calculated risk of severe injury by the OSISP algorithm. It is important to point out that this App is a IT-solution to evaluate the OSISP algorithm in a clinical study. Therefore, Figure 4.11 is just an example of how the clinical decision could look like. Nevertheless, by no means, this recommendation should be taken into consideration for triage protocol and therefore this screen will be removed for the clinical study. The button *Continue* would bring the user to the last screen.

4.1.7 Screen 7: Upload



(a) An Overview of the design.

(b) A warning alert dialog is displayed if uploading request is repeated.

(c) A warning alert dialog is displayed if going back is requested.

Figure 4.12: Screen 7: Upload.

In the last screen, the App logs the data in file format to a server via an FTP implementation. Data is sent through a mobile network or WiFi and automatically uploaded to the server when a network becomes available. In order to do so, the *Upload* button has to be clicked. The hint *Click the button to upload the information* pretends to help the user to carry out the task.

In order to avoid several uploading requests for the same information, an information alert dialog is displayed if the button *Upload* is clicked more than once. In addition, to simplify the App usability and avoid data overwriting, when the button *Back* is clicked a warning alert dialog is displayed informing the user that in such a case *The information would need to be re-introduced again.*

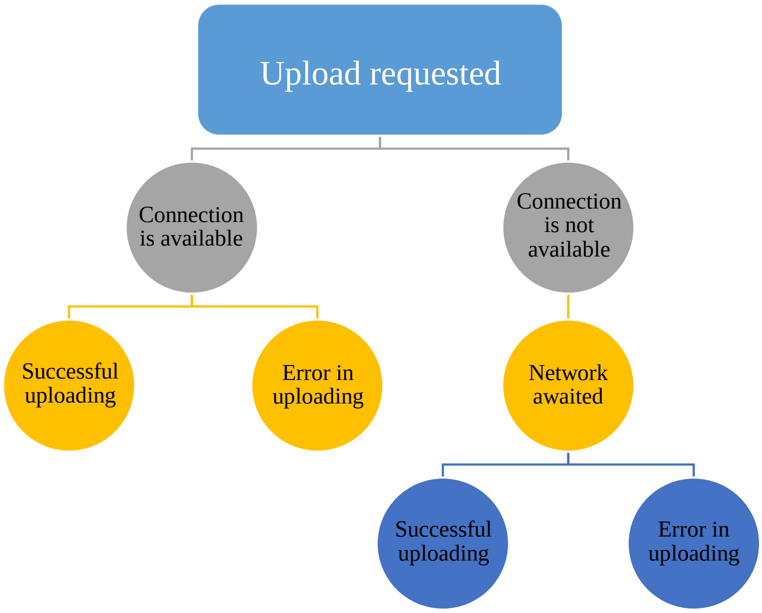
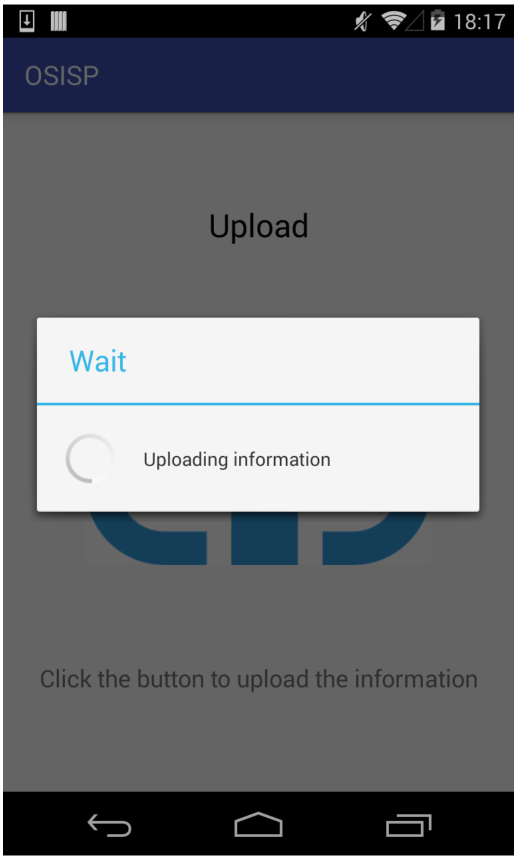


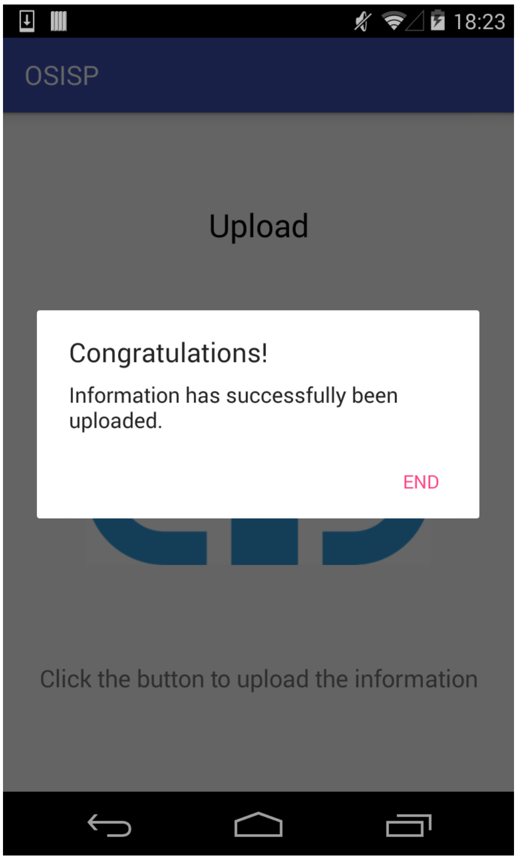
Figure 4.13: An overview of the uploading process.

Figure 4.13 illustrates an overview of the uploading process, where network connection has a main role in the success of the request. Therefore, two main branches connection have been defined depending on network availability.

4.1.7.1 Network available



(a) A process dialog is displayed during Uploading process.

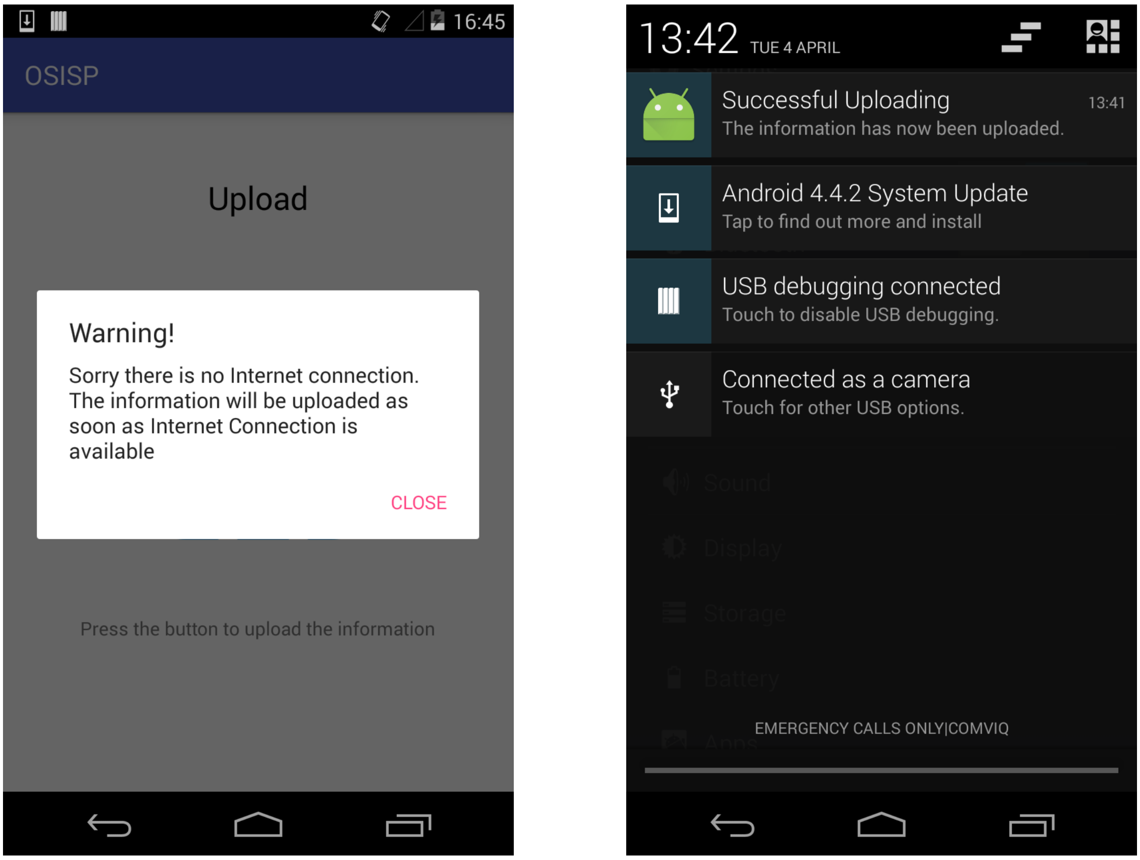


(b) A congratulation alert dialog is displayed if uploading process is successful.

Figure 4.14: Uploading process with available network connection.

If mobile network or WiFi is available when uploading is requested, a process dialog pops up during the waiting time while the information is being sent (Figure 4.14a). When *The information has successfully been uploaded*, a congratulation alert dialog is displayed (Figure 4.14b). If the button *End* is clicked the App is automatically closed.

4.1.7.2 Network not available



(a) A warning alert dialog is displayed if network not available.

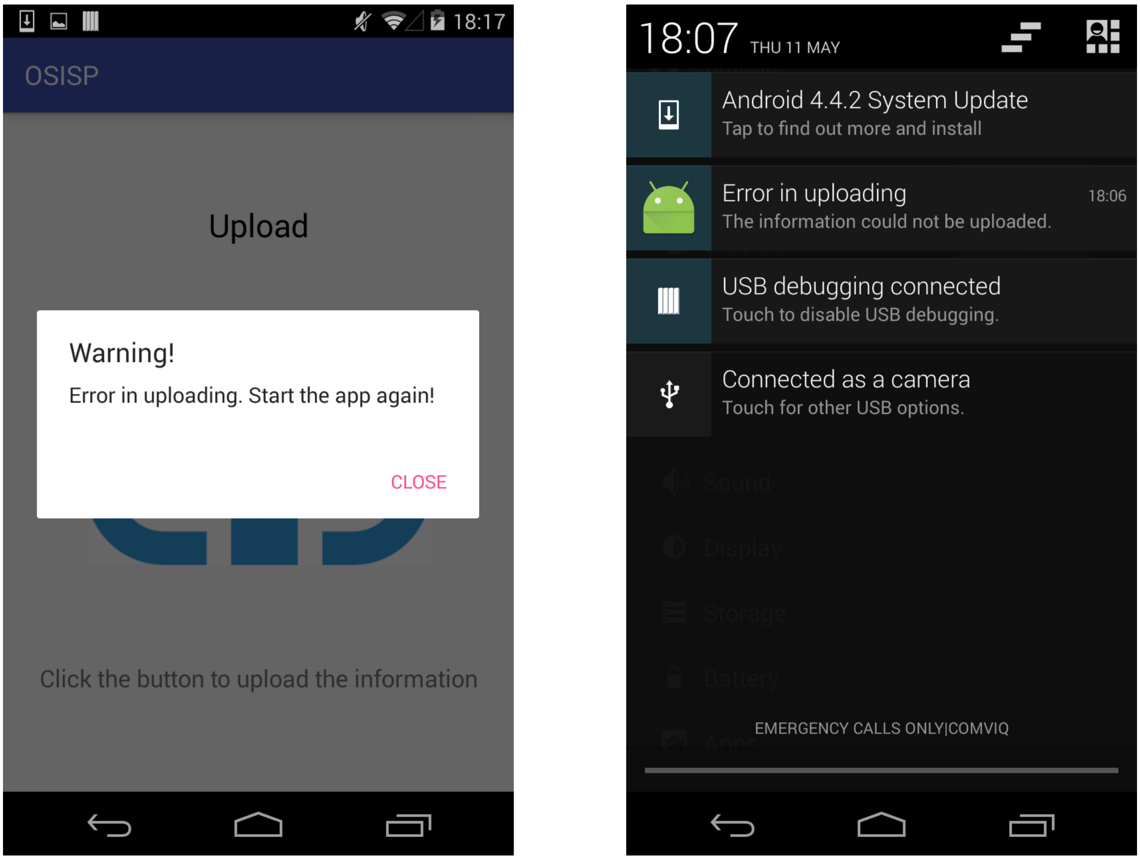
(b) A notification is received when uploading process has successfully been carried out.

Figure 4.15: Uploading process without available network connection.

Network connection might not be always available (Figure 4.15a). In rural or remote areas, network connectivity is often slow and unstable due to lack of base radio stations. In order to overcome this situation, data is momentarily saved in an XML file of the app (so-called *Shared Preferences*) and the user is informed about the problem with warning alert dialog,*Sorry there is no Internet connection. The information will be uploaded as soon Internet connection is available.* The implementation of a connectivity broadcast receiver in the App enables to detect any change in the connectivity. Whenever a broadcast is sent, the system routes broadcasts to the OSISP App, that has subscribed to receive that particular type of broadcast, and trigger a defined event such as the uploading process.

Since recovering network connectivity might take a while, the case where the app is left in the background has been considered. The user should not have to await the App to complete the task to return to his work and might put the smartphone back in the pocket. Therefore, a notification system has been implemented to notify the user when the data has been *Successfully uploaded* to the server. The notification message can be seen in Figure 4.15b.

4.1.7.3 Error in Uploading



(a) A warning alert dialog is displayed if uploading process is disrupted.

(b) An error notification is sent if the App is in the background.

Figure 4.16: Error is faced during the uploading process.

Uploading process could sometimes deal with FTP request or server login issues. In such cases, the user is informed about a wrong uploading process. If the app is being used in that particular moment a warning dialog alert is displayed asking the user to *Start the app again*. The button *Close* automatically closes the App. If the app is in the background, a notification is sent instead.

4.2 Storage of the information

When the information is successfully transferred to the remote server, the file is saved in a directory called *Clinical study*. Different accidents, which might have one or several patients, are distinguished by their title. The title corresponds to the date and time from the first patient registered in each accident.

In order to analyze the data, the researcher will remotely access to that information through the open source software FileZilla Client. As it can be seen in Figure 4.18, the interface, when connecting the server, is divided into two columns. The right one, highlighted in green, represents the remote site, where uploaded files are saved in the *Clinical Study* directory. The left column instead, highlighted in red, represents the local site where files are downloaded to the desired folder. In this case, it is also called *Clinical Study*.

Data can be opened in a text file. The structure of the data, which is defined in detail in Section 3.5, can be observed in Figure 4.17, where all variables and corresponding chosen levels are displayed. In the case of Figure 4.17 no information has been provided for any of the variables. However, a probability of being injured and a recommended destination has been provided. As it is mentioned in Section 3.3, whenever the value of a variable is missing, the most probable level is chosen in order to calculate the risk of severe injury.

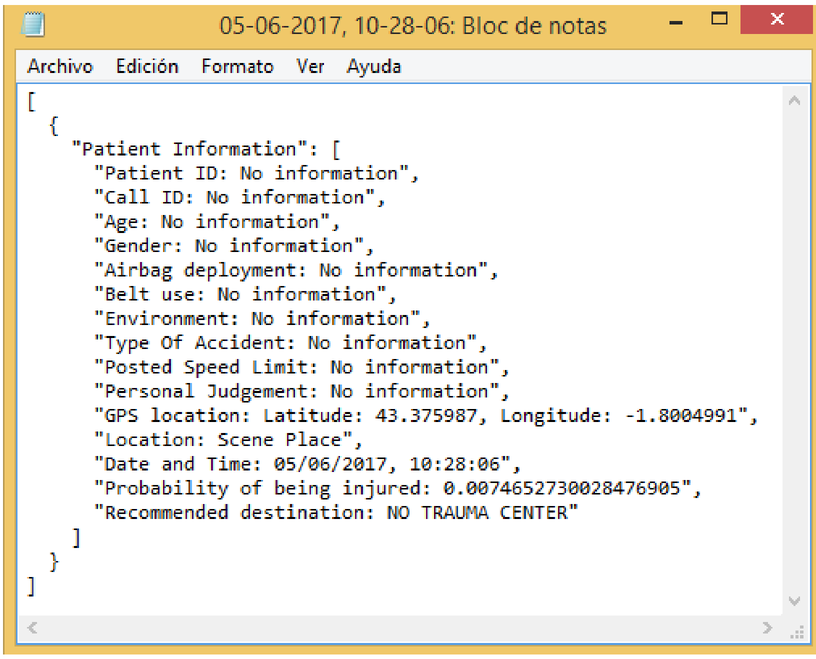


Figure 4.17: Structure of the data.

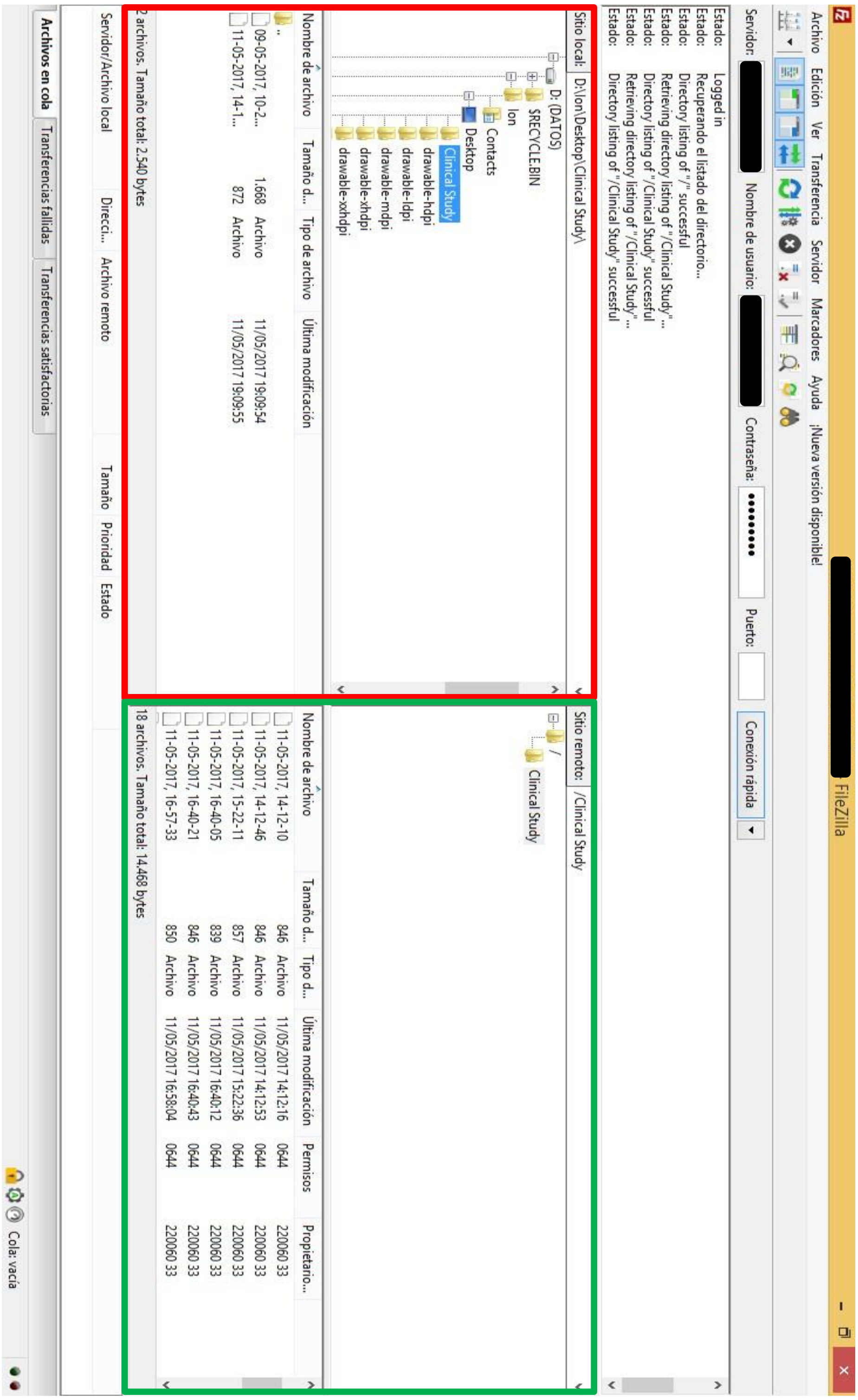
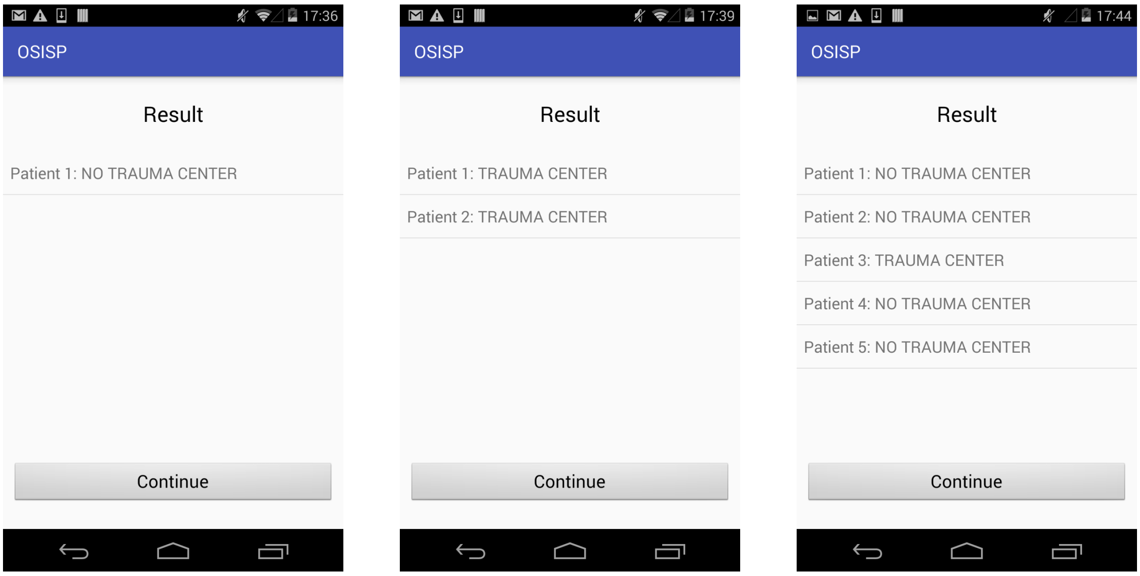


Figure 4.18: Data from the server is accessed through FileZilla Client. The right column represents the server site (Green box). The left column represents the local site (Red box).

4.3 Test of Use Cases

According to the suggested Use Cases, the App determines a recommended destination based on the OSISP algorithm. Figure 4.19 shows how the result is displayed on the smartphone. It is important to emphasize that this screen will be removed for the clinical study.



(a) Recommended destination for Use Case 1.

(b) Recommended destination for Use Case 2.

(c) Recommended destination for Use Case 3.

Figure 4.19: Recommended destinations provided by the App for the three different Use Cases proposed.

4.3.1 Use Case 1

Based on to the description of the accident, Table 4.1 contains the values that have been set as AC for the OSISP algorithm to calculate the risk of severe injury of the patient in Use case 1. Variables *Seat Position* and *Period*, that have been fixed to most probable levels, are also included in order to run the algorithm.

Table 4.1: AC of Patient 1:Use Case 1

Variable	Level	θ
Constant		$\theta_0 = -5.1$
Gender	*Male*	$\theta_1 = 0$
Age	*Under 55*	$\theta_2 = 0$
Airbag deployment	*Not deployed*	$\theta_3 = 0$
Belt use	*Belted*	$\theta_4 = -2.1$
Type of Accident	*Rear End*	$\theta_5 = 0$
Environment	*Urban*	$\theta_6 = 0$
Posted Speed Limit	*50km/h*	$\theta_7 = 0.60$
Fixed Variable *Seat position*	*Front*	$\theta_1 = 0$
Fixed Variable *Period*	*2007-2013*	$\theta_1 = -0.87$

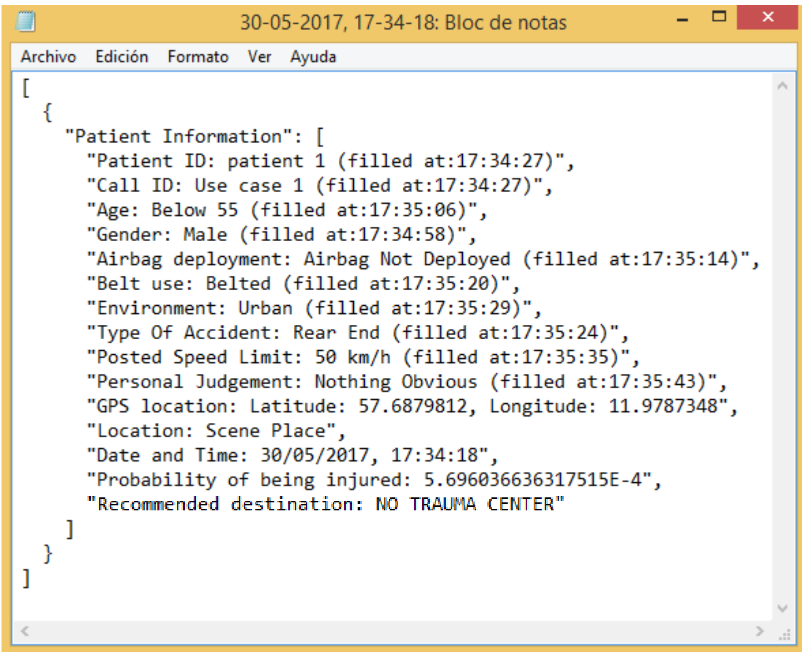


Figure 4.20: Structure of the data of Use Case 1 in the text file uploaded to the server.

Figure 4.20 represents the text file downloaded from the server and containing the data related to the patient. The title of the file corresponds to the date and time of the registered patient. As it can be observed, the user has been able to provide both a *Patient Id* and a *Call Id*. This allows patient identification in order to ask consent for future use of the data. Network connectivity has enabled to record the

GPS coordinates while the user has been running the App. Since the App has been used at the *Scene Place*, the crash scene can be located. The rest of AC are correctly registered and a time stamp is added to keep track of the path used by the user. According to the equation (2.3), the patient would have a probability around 5.7 E-4 of being severely injured. Based on the threshold established in Section 3.3, the algorithm recommends bringing the patient to a *NO TRAUMA CENTER*.

4.3.2 Use Case 2

As in Use Case 1, Table 4.2 and 4.3 contain the values that have been set as AC for the OSISP algorithm to calculate the risk of severe injury of the patient 1 and patient 2 respectively. No information is available regarding the variable *Age* of patient 1. Since the age of the patient is not confirmed, no assumption is made and the variable level is not introduced.

Table 4.2: AC of Patient 1-Use Case 2

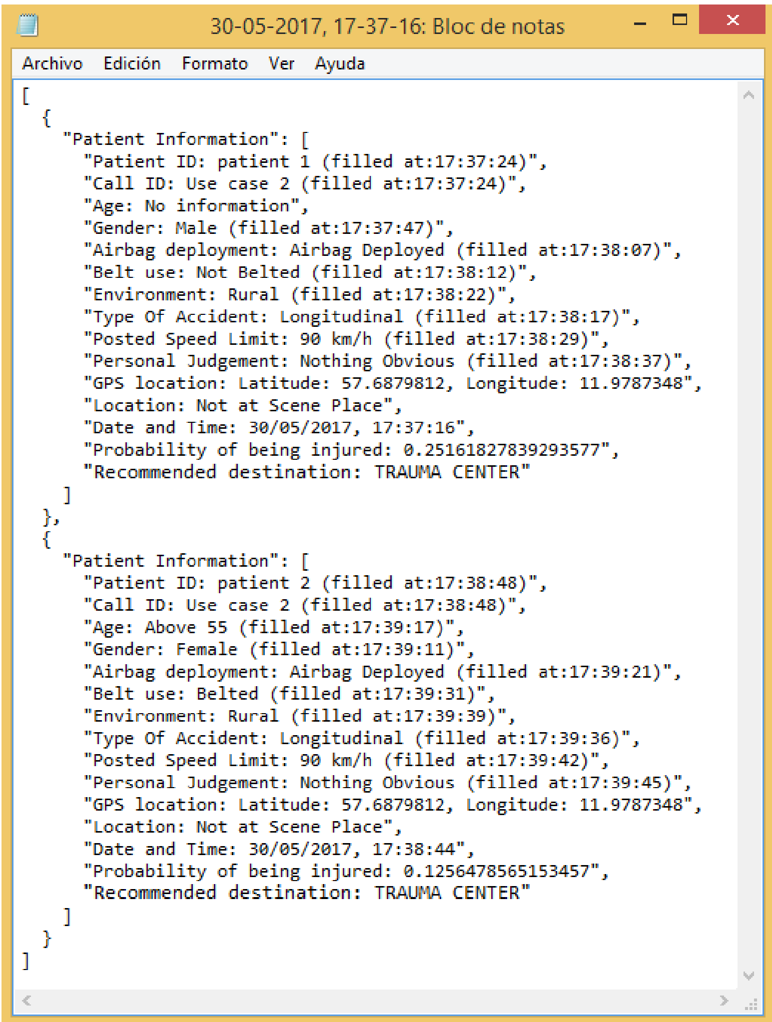
Variable	Level	θ
Constant		$\theta_0 = -5.1$
Gender	*Male*	$\theta_1 = 0$
Age	*No information*	$\theta_2 = 0$
Airbag deployment	*Deployed*	$\theta_3 = 0.1$
Belt use	*Not belted*	$\theta_4 = 0$
Type of Accident	*Longitudinal*	$\theta_5 = 2.7$
Environment	*Rural*	$\theta_6 = 0.58$
Posted Speed Limit	*90km/h*	$\theta_7 = 1.5$
Fixed Variable *Seat position*	*Front*	$\theta_1 = 0$
Fixed Variable *Period*	*2007-2013*	$\theta_1 = -0.87$

Table 4.3: AC of Patient 2-Use Case 2

Variable	Level	θ
Constant		$\theta_0 = -5.1$
Gender	*Female*	$\theta_1 = 0.33$
Age	*Above 55*	$\theta_2 = 0.92$
Airbag deployment	*Deployed*	$\theta_3 = 0.1$
Belt use	*Belted*	$\theta_4 = -2.1$
Type of Accident	*Longitudinal*	$\theta_5 = 2.7$
Environment	*Rural*	$\theta_6 = 0.58$
Posted Speed Limit	*90km/h*	$\theta_7 = 1.5$
Fixed Variable *Seat position*	*Front*	$\theta_1 = 0$
Fixed Variable *Period*	*2007-2013*	$\theta_1 = -0.87$

Figure 4.21 displays the data of the text file downloaded from the server. Patients are saved from top to bottom. *Patient Id* and *Call Id* enable to identify and distinguish both patients. The title of the file corresponds to the date and time of the

first registered patient. Network connectivity has allowed GPS coordinates to be registered. However, the additional information noting that the App has not been run in the crash scene enables the researcher to know that GPS coordinates do not correspond to the location of the accident. All variables are correctly registered and time stamped. The equation (2.3) predicts that patient 1 has a probability of 0.25 of being severely injured while the patient 2 would get 0.13. Since both patients have a probability higher than the threshold, *TRAUMA CENTER* is recommended.


30-05-2017, 17-37-16: Bloc de notas

Archivo Edición Formato Ver Ayuda


```
[
  {
    "Patient Information": [
      "Patient ID: patient 1 (filled at:17:37:24)",
      "Call ID: Use case 2 (filled at:17:37:24)",
      "Age: No information",
      "Gender: Male (filled at:17:37:47)",
      "Airbag deployment: Airbag Deployed (filled at:17:38:07)",
      "Belt use: Not Belted (filled at:17:38:12)",
      "Environment: Rural (filled at:17:38:22)",
      "Type Of Accident: Longitudinal (filled at:17:38:17)",
      "Posted Speed Limit: 90 km/h (filled at:17:38:29)",
      "Personal Judgement: Nothing Obvious (filled at:17:38:37)",
      "GPS location: Latitude: 57.6879812, Longitude: 11.9787348",
      "Location: Not at Scene Place",
      "Date and Time: 30/05/2017, 17:37:16",
      "Probability of being injured: 0.25161827839293577",
      "Recommended destination: TRAUMA CENTER"
    ]
  },
  {
    "Patient Information": [
      "Patient ID: patient 2 (filled at:17:38:48)",
      "Call ID: Use case 2 (filled at:17:38:48)",
      "Age: Above 55 (filled at:17:39:17)",
      "Gender: Female (filled at:17:39:11)",
      "Airbag deployment: Airbag Deployed (filled at:17:39:21)",
      "Belt use: Belted (filled at:17:39:31)",
      "Environment: Rural (filled at:17:39:39)",
      "Type Of Accident: Longitudinal (filled at:17:39:36)",
      "Posted Speed Limit: 90 km/h (filled at:17:39:42)",
      "Personal Judgement: Nothing Obvious (filled at:17:39:45)",
      "GPS location: Latitude: 57.6879812, Longitude: 11.9787348",
      "Location: Not at Scene Place",
      "Date and Time: 30/05/2017, 17:38:44",
      "Probability of being injured: 0.1256478565153457",
      "Recommended destination: TRAUMA CENTER"
    ]
  }
]
```


Figure 4.21: Structure of the data of Use Case 2 in the text file uploaded to the server.

4.3.3 Use Case 3

AC of patient 1 (Table 4.4), patient 2 (Table 4.4), patient 3 (Table 4.4), patient 4 (Table 4.4) and patient 5 (Table 4.4) have been recorded and displayed. However, level of variables vary among the casualties. Since no information regarding the variable *Age* of the first patient has been registered, the most probable level (*Under 55*) is set. Due to accident characteristics, the *Type of Accident* of the car causing the crash has been considered as *Single* (the vehicle collides with stationary object or departs from the road), while the rest of involved vehicles are set to *Rear End* (a vehicle impacts another one from behind).

Table 4.4: AC of Patient 1-Use Case 3

Variable	**Level**	θ
Constant		$\theta_0 = -5.1$
Gender	*Male*	$\theta_1 = 0$
Age	*No information*	$\theta_2 = 0$
Airbag deployment	*Deployed*	$\theta_3 = 0.1$
Belt use	*Belted*	$\theta_4 = -2.1$
Type of Accident	*Single*	$\theta_5 = 1.6$
Environment	*Rural*	$\theta_6 = 0.58$
Posted Speed Limit	*100km/h*	$\theta_7 = 0.85$
Fixed Variable *Seat position*	*Front*	$\theta_1 = 0$
Fixed Variable *Period*	*2007-2013*	$\theta_1 = -0.87$

Table 4.5: AC of Patient 2-Use Case 3

Variable	θ	
Constant		$\theta_0 = -5.1$
Gender	*Female*	$\theta_1 = 0.33$
Age	*Under 55*	$\theta_2 = 0$
Airbag deployment	*Deployed*	$\theta_3 = 0.1$
Belt use	*Belted*	$\theta_4 = -2.1$
Type of Accident	*Rear End*	$\theta_5 = 0$
Environment	*Rural*	$\theta_6 = 0.58$
Posted Speed Limit	*100km/h*	$\theta_7 = 0.85$
Fixed Variable *Seat position*	*Front*	$\theta_1 = 0$
Fixed Variable *Period*	*2007-2013*	$\theta_1 = -0.87$

Table 4.6: AC of Patient 3-Use Case 3

Variable	**Level**	θ
Constant		$\theta_0 = -5.1$
Gender	*Male*	$\theta_1 = 0$
Age	*Under 55*	$\theta_2 = 0$
Airbag deployment	*Deployed*	$\theta_3 = 0.1$
Belt use	*Not belted*	$\theta_4 = 0$
Type of Accident	*Rear End*	$\theta_5 = 0$
Environment	*Rural*	$\theta_6 = 0.58$
Posted Speed Limit	*100km/h*	$\theta_7 = 0.85$
Fixed Variable *Seat position*	*Front*	$\theta_1 = 0$
Fixed Variable *Period*	*2007-2013*	$\theta_1 = -0.87$

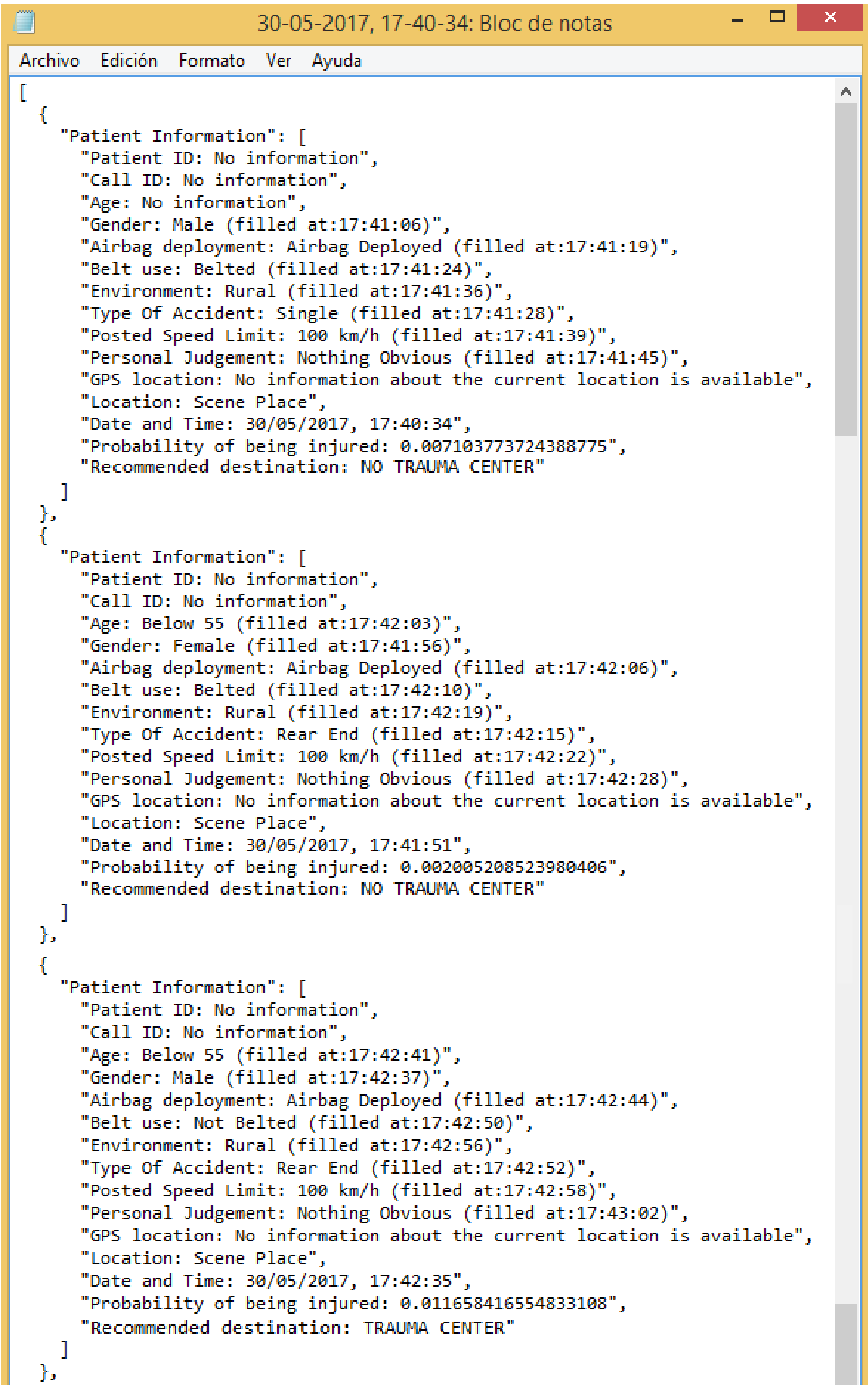
Table 4.7: AC of Patient 4-Use Case 3

Variable	Level	θ
Constant		$\theta_0 = -5.1$
Gender	*Male*	$\theta_1 = 0$
Age	*Under 55*	$\theta_2 = 0$
Airbag deployment	*Deployed*	$\theta_3 = 0.1$
Belt use	*Belted*	$\theta_4 = -2.1$
Type of Accident	*Rear End*	$\theta_5 = 0$
Environment	*Rural*	$\theta_6 = 0.58$
Posted Speed Limit	*100km/h*	$\theta_7 = 0.85$
Fixed Variable *Seat position*	*Front*	$\theta_1 = 0$
Fixed Variable *Period*	*2007-2013*	$\theta_1 = -0.87$

Table 4.8: AC of Patient 5-Use Case 3

Variable	Level	θ
Constant		$\theta_0 = -5.1$
Gender	*Female*	$\theta_1 = 0.33$
Age	*Above 55*	$\theta_2 = 0.92$
Airbag deployment	*Deployed*	$\theta_3 = 0.1$
Belt use	*Belted*	$\theta_4 = -2.1$
Type of Accident	*Rear End*	$\theta_5 = 0$
Environment	*Rural*	$\theta_6 = 0.58$
Posted Speed Limit	*100km/h*	$\theta_7 = 0.85$
Fixed Variable *Seat position*	*Front*	$\theta_1 = 0$
Fixed Variable *Period*	*2007-2013*	$\theta_1 = -0.87$

Figure 4.22 and 4.23 display the text file downloaded from the server. Data regarding all patients of the accident are saved in the same file. However, no identification has been provided to any patient. In order to distinguish patients belonging to the same accident, the date and time of recording is saved. The title of the file corresponds to the date and time of the first registered patient. The App has been used in the scene of the accident. However, network unavailability has disabled GPS coordinates recording and accident location. All AC have been correctly registered and time stamped. Based on the equation (2.3), the probability of being severely injured is 0.007, 0.002, 0.012, 0.001 and 0.005 respectively. Therefore, for patient 3, whose probability is over the threshold and for whom *TRAUMA CENTER* is recommended. For the rest of the patients, *NO TRAUMA CENTER* is required.




```
[
  {
    "Patient Information": [
      "Patient ID: No information",
      "Call ID: No information",
      "Age: No information",
      "Gender: Male (filled at:17:41:06)",
      "Airbag deployment: Airbag Deployed (filled at:17:41:19)",
      "Belt use: Belted (filled at:17:41:24)",
      "Environment: Rural (filled at:17:41:36)",
      "Type Of Accident: Single (filled at:17:41:28)",
      "Posted Speed Limit: 100 km/h (filled at:17:41:39)",
      "Personal Judgement: Nothing Obvious (filled at:17:41:45)",
      "GPS location: No information about the current location is available",
      "Location: Scene Place",
      "Date and Time: 30/05/2017, 17:40:34",
      "Probability of being injured: 0.007103773724388775",
      "Recommended destination: NO TRAUMA CENTER"
    ]
  },
  {
    "Patient Information": [
      "Patient ID: No information",
      "Call ID: No information",
      "Age: Below 55 (filled at:17:42:03)",
      "Gender: Female (filled at:17:41:56)",
      "Airbag deployment: Airbag Deployed (filled at:17:42:06)",
      "Belt use: Belted (filled at:17:42:10)",
      "Environment: Rural (filled at:17:42:19)",
      "Type Of Accident: Rear End (filled at:17:42:15)",
      "Posted Speed Limit: 100 km/h (filled at:17:42:22)",
      "Personal Judgement: Nothing Obvious (filled at:17:42:28)",
      "GPS location: No information about the current location is available",
      "Location: Scene Place",
      "Date and Time: 30/05/2017, 17:41:51",
      "Probability of being injured: 0.002005208523980406",
      "Recommended destination: NO TRAUMA CENTER"
    ]
  },
  {
    "Patient Information": [
      "Patient ID: No information",
      "Call ID: No information",
      "Age: Below 55 (filled at:17:42:41)",
      "Gender: Male (filled at:17:42:37)",
      "Airbag deployment: Airbag Deployed (filled at:17:42:44)",
      "Belt use: Not Belted (filled at:17:42:50)",
      "Environment: Rural (filled at:17:42:56)",
      "Type Of Accident: Rear End (filled at:17:42:52)",
      "Posted Speed Limit: 100 km/h (filled at:17:42:58)",
      "Personal Judgement: Nothing Obvious (filled at:17:43:02)",
      "GPS location: No information about the current location is available",
      "Location: Scene Place",
      "Date and Time: 30/05/2017, 17:42:35",
      "Probability of being injured: 0.011658416554833108",
      "Recommended destination: TRAUMA CENTER"
    ]
  },
```


Figure 4.22: Structure of the data of Use Case 3 in the text file uploaded to the server. Information belonging to patient 1, patient 2 and patient 3.

```
{
  "Patient Information": [
    "Patient ID: No information",
    "Call ID: No information",
    "Age: Below 55 (filled at:17:43:15)",
    "Gender: Male (filled at:17:43:08)",
    "Airbag deployment: Airbag Deployed (filled at:17:43:19)",
    "Belt use: Belted (filled at:17:43:23)",
    "Environment: Rural (filled at:17:43:30)",
    "Type Of Accident: Rear End (filled at:17:43:27)",
    "Posted Speed Limit: 100 km/h (filled at:17:43:32)",
    "Personal Judgement: Nothing Obvious (filled at:17:43:34)",
    "GPS location: No information about the current location is available",
    "Location: Scene Place",
    "Date and Time: 30/05/2017, 17:43:06",
    "Probability of being injured: 0.0014424049616425206",
    "Recommended destination: NO TRAUMA CENTER"
  ]
},
{
  "Patient Information": [
    "Patient ID: No information",
    "Call ID: No information",
    "Age: Above 55 (filled at:17:43:46)",
    "Gender: Female (filled at:17:43:41)",
    "Airbag deployment: Airbag Deployed (filled at:17:43:48)",
    "Belt use: Belted (filled at:17:43:52)",
    "Environment: Rural (filled at:17:43:58)",
    "Type Of Accident: Rear End (filled at:17:43:55)",
    "Posted Speed Limit: 100 km/h (filled at:17:44:00)",
    "Personal Judgement: Nothing Obvious (filled at:17:44:03)",
    "GPS location: No information about the current location is available",
    "Location: Scene Place",
    "Date and Time: 30/05/2017, 17:43:39",
    "Probability of being injured: 0.005016468428524052",
    "Recommended destination: NO TRAUMA CENTER"
  ]
}
]
```


Figure 4.23: Structure of the data of Use Case 3 in the text file uploaded to the server. Information belonging to patient 4 and patient 5.

4.4 Cyclic software development: Use of Semi-structured Interviews

Semi-structured interviews have provided a deeper perspective of the usability and performance of the App, as well as different suggestions in order to improve its design. Only the most relevant points are going to be presented in this section. Full interviews are available in Appendix A.1.

In general, all interviewees have a really good impression of the App. They consider it quick, intuitive and easy to use. Essential characteristics to enable its integration into the ambulance nurse workflow. Previous ideas such as fixing the portrait mode to avoid both hands being occupied when using the App have been considered as convenient characteristics. Furthermore, some other valuable recommendations concerning the structure and design of the App have been taken into consideration and implemented throughout the development process (See Appendix A.1 for more precise information).

The most significant modification, again suggested by some of the interviewees, is the possibility of adding more than one casualty without having to start the App more than once. Since each victim is assessed by one ambulance, handling them as different cases has been considered. However, based on their experience, the leading ambulance, which is the responsible for reporting the crash scene and giving priority to casualties, could play this role. The option of adding several victims could facilitate the task.

Not only as a user but also as a researcher point view, Bengt-Arne Sjöqvist has provided meaningful information related to App testing and data structure.

5

Discussion

5.1 Statement and implication of the obtained results

According to the results, the OSISP App seems to be a complete working solution for a clinical study and evaluation of the algorithm. Experts in prehospital care have verified that the OSISP App is quick, clear and easy to use. In addition, their recommendations have been taken into account. Iterative feedback has enabled continuous refinements in the design and performance of the app. The possibility to triage several patients at the same time appears to be an added benefit that facilitates the usability of the OSISP App.

Data is saved in the server, which can then be remotely accessed by the researcher via FileZilla client. Files are easily distinguishable and are classified by the date and time. This would allow, in case no identification is provided, to identify the patients and ask for consent. Information of the patients involved in the accident is structured by using the JSON format, which is commonly used for exchanging data. In order to efficiently transmit and access information of the patients by hospital members, standardization of recorded information might be the most convenient choice for mutual understanding. Therefore, the use of a standardized data structure for data acquisition in prehospital care has been taken into consideration when developing the OSISP App. However, due to the small amount of data and since the main purpose is to design a solution to evaluate the algorithm in a clinical study, standardized clinical health structures have been discarded. The election has been made based on literature review and feedback from semi-structured interviews. However, if the OSISP algorithm is successfully evaluated, standards such as SNOMED-CT or NEMSIS should be considered for future processes [31, 32].

The correct implementation of the algorithm in the OSISP App has been demonstrated by performing three different Use Cases. According to the model, expected risk injury probabilities have been obtained. An example of how the clinical decision support could look like is presented by displaying the recommended destination. However, that will be removed and not be used in the clinical study.

The model provides a clinical decision support based on cutoff value. Considering Table 3.3, it can be observed that a high specificity, meaning a small population of FP (less non-severely injured patients identified as severely injured) involves a decrease in the sensitivity, meaning a bigger population of FN (more severely injured patients identified as non-severely).

Literature proposes different methods to define a cutoff value for handling different levels of undertriage or overtriage. According to the expert panel [8, 14], a threshold probability cutpoint of 0.20 should be used as injury severity predictor. [33] made use of this recommendation to test and validate their logistic regression model for ISP, achieving 40% and 98% of sensitivity and specificity respectively. Furthermore, based on the American College of Surgeons' recommendations, [34] also develop an Advanced Automatic Crash Notification algorithm achieving sensitivity (>95%) and specificity (>50%). Alternatively, [35] discuss the possibility of using 0.10 as threshold despite its lower specificity. According to Bahouth and associates' findings, the improved selectivity provided by the 0.10 threshold warrants its application in the field.

The aim of the OSISP algorithm is to improve the current low accuracy of triage in road crashes patients by reducing the undertriage. In order to obtain low levels of undertriage, a high sensitivity is needed. However, both thresholds of 0.10 and 0.20 do not always guarantee such a property since both sensitivity and specificity depend on the developed model. [36] considers as a *"next-to-ideal"* values no undertriage and 15-20% of overtriage. Nevertheless, this result is unfeasible according to the curves of the proposed model in Figure 1.3. Therefore, a cutoff value (p=0.0082) which corresponds to a target specificity and sensitivity of 50% and 90% respectively has been chosen. In practice, this threshold would be established by experts.

Since Google Play is an open source on-line store App, a code has to be provided when the OSISP app is installed in order to avoid undesirable users. This code will be decided by the researcher and privately given to users.

5.2 Limitations of the project

Some variables from the algorithm developed by [3] appeared to be statistically not significant to predict injury severity. *Seat position*, which is weakly related to the probability of being severely injured, has not been included in the App. However, in order to obtain a probability and a clinical decision, a value corresponding to this variable has to be introduced. In the same way, the variable *Period* (regarding the time of the accident) has to be fixed. Furthermore, when some AC are not feasible to assess, the most probable levels are assumed. This could affect in the recommendation provided by the App.

In the case of the period, the gender, the age, the seat position, the airbag deployment and the use of the belt, the most probable levels coincide with the less risky case. On the other hand, for the environment, the posted speed limit and the type of accident, setting the value to the most probable level does not guarantee the least risky case. Therefore, it can be concluded that the decision of choosing the most probable levels when information is missing can lead to some degree of undertriage.

Loss of the mobile phone could lead to undesirable users uploading irrelevant information for the clinical study. Therefore, the possibility of a login process or making the use of the code continuous might be considered. In this thesis, an implementation of the algorithm has been developed for use in Android smartphones. This could affect the clinical study performance due to the amount of iOS (or other operating systems) smartphones in the market.

6
Conclusion

A complete working IT-solution for clinical study and evaluation of the OSISP algorithm for patient triage in road crashes has been developed. Based on experts feedback, it has been designed to naturally fit into the normal workflow of the ambulance care. The OSISP App records AC provided by the user to calculate the risk of severe injury. Although in practice the cutoff value of the OSISP algorithm that dichotomize severe and non-severe patients will be defined by experts, for the IT-solution a target of 90% sensitivity and 50% specificity was implemented. Based on the literature, the chosen targets were considered to improve the current low accuracy of triage in road patients by reducing the undertriage level. Through a mobile network, the data is sent to a server, via a File Transfer Protocol implementation, which is then remotely accessed by the researcher. If the solution is successfully evaluated in a clinical study, the ambition is to integrate the algorithm in other ambulance ICT-platforms.

7

Future Work

7.1 Give solution to identified limitations

In order to improve the performance and usability of the IT-solution, limitations mentioned in Section 5.2 should be solved. The variables *Seat position* and *Period* were fixed and the user did not have the option to change their level. Even if their effects might not be determinant for the clinical study due to their low significance (Odd Ratio (OR) close to one), the model should be modified in order to provide a more concise prediction. In addition, it was demonstrated that fixing missing variables to the most probable levels could lead to undertriage. Therefore, setting the riskiest levels instead might be considered to overcome this limitation. This solutions could considerably improve the quality of the final application.

7.2 Addition of new characteristics

New AC could be added in the future. According to users' feedback during the clinical study, new features or even improvements of currently existing ones could be implemented. GPS tracking of closest required medical center could be one example. Based on the risk injury probability calculated by the OSISP algorithm and the corresponding injury severity classification, the OSISP App could track the closest required medical center. This feature would facilitate and minimize the transport and delivery of the patient in the prehospital care and would subsequently reduce the mortality and mitigate further disabilities.

7.3 Participants' anonymity, confidentiality and privacy

Recording AC when running the App might give rise to patient's rejection who would be the implicit user. A collection of data and relating it to somebody according to a patient ID could be sensitive and intrusive.

Indeed, any good research practice in human subjects has to consider subjects' anonymity, confidentiality and privacy. Therefore, according to [37], those three terms that can be defined as follows, should be taken into consideration for the clinical evaluation:

Anonymity: Collected information has no related identifiers, such as name, address or telephone number, or cannot be linked to participants' identities.

Confidentiality: Concerned about the treatment of information, it consist in an agreement between researcher and participants that the research team is the only one having access to data and relating information to participants' identities. Therefore, disclosure of data is strongly avoided based on a trust relationship.

Privacy: Concerned about people, it is related to interest of participants in controlling the extent, timing and circumstances of sharing their personal information with others.

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A

Appendix 1

A.1 Semi-structured Interviews

A.1.1 First Interview: Robert Höglind

Q: Could you give us some feedback on the OSISP app and its keys of acceptability?

A: The app is intuitive, easy to use and seems to adapt to the typical work-flow of a paramedic. However, in order to improve the app, I would remove the reminder of scene safety at the beginning. It is not necessary since scene safety is always ensured. In the menu, showing "the actual choice" rather than "completed" in the checkbox text would facilitate the use of the app. With the same purpose, I would prefer to go back directly to the menu when choosing an option instead of having to save it each time.

Q: Should the OSISP app be fixed in portrait mode in order to avoid the use of landscape to allow the user have a free hand at all times?

A: In my opinion that could be a good option but if I were you I would ask somebody else to ensure your suggestion.

Q: Are you provided with working smartphones? How are phones distributed and accessed? Does each worker have his/her own phone? Is there any user identification?

A: Each unit is usually provided with one mobile-phone. However, it does not have to be a smartphone even if nowadays most of them they are.

Q: Does a paramedic assist more than one casualty at an accident scene? Or is one paramedic assigned to one victim?

A: In a scene with multiple victims a leading ambulance makes the triage and takes the role of coordinator. The rest of ambulances treat the patients. If possible, there is always one ambulance in charge of each patient.

A.1.2 Second Interview: Bengt Arne Sjöqvist

Q: Could you give us some feedback on the OSISP app and its keys of acceptability?

A: The app looks good and easy to use. In order to guarantee data privacy, a log-in process could be an option but it looks good as it is. This is something you should ask experienced ambulance nurses since it might not adapt to their workflow.

Q: How should the data be structured? Should I follow some kind of standards?

A: Since the app is currently designed to gather data and design a clinical decision support, it might be not necessary to follow a standardized data structure for now. An understandable and clear way to store the data would be enough in order later to work with it.

Q: How would you prove effectiveness and performance reliability of the app?

A: The best way is to ask experienced ambulance nurses to give you some feedback. They will be the future users of the app and there is nobody better than them to test the app. Another solution might be to think about different real scenarios or use cases and see if the app would adapt and perform well in all those situations.

Q: Do you have any other comment?

A: From my experience, I think it could be a good idea to implement a time stamp that registers the way the user has provided the information. This way you would be able to see if they get stuck somewhere in the app and this would give you some kind of feedback. It is true that in this app the amount of information is not very big but it could be helpful.

A.1.3 Third Interview: Magnus Andersson Hagiwara

Q: Could you give us some feedback on the OSISP app and its keys of acceptability?

A: The app is easy and quick to use. I don't think the ambulance personnel would have any problem in using it. I think it would be nice to implement it in another kind of software in the ambulance.

Q: What do you think about fixing the portrait mode to avoid both hands to be occupied when using the app?

A: I think it is a good idea.

Q: Do you think the app would fit in a real scenario and adapt to user's workflow?

A: Ambulance personnel is looking for something easy and quick to use. If you achieve this, you will get much more tolerance for using it among them.

Q: How do you usually act in real accident scenario?

A: A first ambulance, the leading one, analyzes the crash scene and collects and reports the information about all the victims. According to that, a priority is given to them. Then, the rest of ambulances assess individually each victim.

Q: Do you have any other comments or observations?

A: In general, as I said, I think it is easy to use. Pictures are big and clear which makes the app very intuitive. Maybe, it would be nice if the menu could be a bit bigger as long as it fits on one screen. If not, it is good as it is. I think another good option for the future would be to report several patients at the same time. This way, the leading ambulance would be able to take this responsibility.

A.1.4 Fourth Interview: Hans Törnqvist

Q: Could you give us some feedback on the OSISP app and its keys of acceptability?

A: It was very easy to use since I have been able to fill it in a few seconds even if it was the first time I use it. I think it would be a good idea to implement it in ambulances in the future. This would allow the leading ambulance to collect information about the patient and send it to dispatch services and hospitals.

Q: What do you think about fixing the portrait mode to avoid both hands to be occupied when using the app?

A: I think it is a good idea. With the portrait mode should be enough.

Q: Do you think the app would fit in a real scenario and adapt to user's workflow?

A: It will as long as it has a purpose and is easy and quick to use. After using it, I honestly think it will.

Q: How do you usually act in real accident scenario?

A: One ambulance is in charge of reporting the information of the accident and giving priority to victims while the rest of ambulances assess the victims.

Q: Do you have any other comments or observations?

A: I think it is okay as it is. As I told you, if it is fast and easy, there should not be any problem. One suggestion would be to remove the button back when filling the accident characteristics in the menu. It can be confusing sometimes.