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Systemic Functions and Research Gaps Addressed when Identifying Persons on the Move Using Mobile Phones at EU Borders

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The number of passengers at EU Schengen borders increases. Also, the need to improve their seamless, performant and secure identification. Ubiquitous smartphones with capable sensors ask to be utilized for the identification as well as digital wallets and digitalized person identities. The paper proposes how to combine biometric services, ID document validation, and additional sensors with smartphone capabilities to identify persons on the move at air, port and sea borders. After pre-registration including the uploading of the digital identity in a digital wallet, taking face and fingerprint images with the phone, person ID document and biometric data is verified. Alternatively, persons can use registration desks, where ID documents are identified and uploaded again as digital identities. At the border, person identification in consent only is conducted. During walk- or drive-through, the mobile phone wallets are localized and identified using ultrasound. Persons are asked to take self-images of their face and fingerprints. In addition, through heartbeat detection person presence is assessed for anonymous body counting and tracing. A remote camera takes images of the face and the activity of self-filming of the face and fingerprints. Along with the process, identification evidence is sparsely collected and securely combined, including for cross-validation. Using a rule and risk-based approach, the uncertainty-aware person identification takes place. The article presents a compact system functional process schematic. It is supported by a tabular summary covering (i) objective of functions, (ii) related key performance indicators, (iii) expected challenges based on state of the art and technology, and (iv) detailed technical system function description allocating the functionality. The approach is motivated with ethic-informed design thinking, reliability and safety functional approaches and by comparing with more detailed semi-formal and tabular approaches. The schematic for smartphone-based identity identification is discussed, and a sample tabular row entry is provided.

Keywords: Person identification at EU borders, Digital wallet on smart mobile phone, On-the-move and drive-through identification, ID document verification, System-level function design thinking, Tabular system level function feasibility assessment, systemic state of technology gap identification, technical solution allocation.

1. Introduction

Design thinking (Waidelich et al. 2018) requires to identify and describe system objectives, related services and functions, how they will improve users' experience, long before moving to system designs that realize such system functions

resorting to the best technological solutions and improved organizational-regulatory frameworks, if not disrupting the latter (Dsouza 2024). The challenge arises how to assess design concepts at early stages arising from design thinking and knowledge accessible in early project phases.

The present paper presents a novel system design for person identification at Schengen borders using smartphones in a key role. This goes beyond ABC-gates and one-stop gates, see, e.g., (Renger et al. 2014) (Jain et al. 2020), with expected performance gains as discussed in (Jain et al. 2023). The paper provides a slim approach to present and assess the key system functions in terms of a diagram schematic of system level functional objectives which is combined with a table providing information on key system functional objectives (SOs), related key performance indicators (KPIs), identified research state of the art and gaps (SotA&G), and last but not least system functional steps realizations in terms of technological or other means (S). The paper provides a system engineering motivation for this approach by resorting to related possible approaches.

Being in the situation that the intended functionality, e.g., in the sense of the SOTIF standard ISO 21448 (ISO 21448 2022), requires in addition safety functions, i.e., e.g., at least one function with safety integrity level 1 (SIL1) according to IEC 61508 (IEC 61508 2010) (Siebold, Larisch, and Häring 2010), and security functionalities, e.g., according to ISO/IEC 27554 (ISO 27554 2024), to achieve pre-defined acceptable safety and security goals in terms of a set of risk acceptance quantities (Rapeli 2023) (Häring 2021e) (Häring 2015b), a standardized design (thinking) approach is to require overall safety and security functions (Häring et al. 2022), which themselves are realized with additional technological hardware (HW) and software (SW) functions or other technologies including organizational means.

Already in the fundamental functional safety standard IEC 61508 the notion of overall safety function requirement is introduced addressing necessary overall risk reduction at system level without distinguishing between underlying functions in detail that ‘allocate’ the overall safety function. This can be understood as design thinking in the safety and reliability domain how to generate reliable functions, even standardized.

The question arises how to assess also the completeness and feasibility of realization as well as the risk of failure of top-level system reliability functions in very early phases of project developments. Such system performance functions, e.g., as described in (Häring, and Schäfer et al. 2021), can be defined as being mainly primary reliability but also secondary safety- and security-related functions, as well as combinations thereof, if reliability functions are safety functions.

It is desirable to assess these system functions at pre-design level, i.e. as abstract as reasonably possible and as detailed as necessary to be able to select best possible technological solutions sufficient for the reliability/performance functions and key safety and security functions.

One could resort to abstract systems modeling languages in the requirements phase such as unified modeling language (UML) (UML 2025) (Hänle and Häring 2008) (Häring 2021c) or more accessible to all engineering sciences to the recently updated systems modeling language (SysML) (SysML 2025) (Larisch et al. 2008) (Larisch, Siebold, and Häring 2009) (Häring 2021d). SysML, when restricted and slightly extended can be used to provide abstract discrete system sate machine models and related formal functional assessments, see e.g. (Siebold, Larisch, and Häring 2009) (Siebold and Häring 2012) (Siebold 2013). However, for instance, in case of SysML in very early design phases one employs SysML requirements diagram (rd) and SysML use case diagram (ucd) only. Only few options beyond some hierarchizations and dependency visualizations that go beyond numbered tabular listings of requirements are accessible when avoiding structural and dynamic SysML modeling.

Instead of rather resource and background-/training-intense formalizable semi-formal approaches, the present paper uses a graphical illustration and a tabular listing to provide an overview of the envisioned key functions of a system concept.

Application example is an on-the-move identification of persons at EU Schengen borders using in consent few camera sensors, an ultrasound localization and communication

system, heart-beat detection and in addition traveler's smartphone's cameras and computation power.

Such a smartphone enabled dynamic border control can be identified as safety relevant system, if not even safety critical. From a standardization perspective, this requires to consider recommended methods and method classes as listed in the above introduced functional safety and security standards. Even more to consider methods recommended by the generic umbrella standard ISO 31000 (ISO 31000 2018) related standards that are applicable to overall risk and resilience control (Häring and Gelhausen 2018) due to its flexibility (Schoppe, Häring, and Siebold 2013) (Finger et al. 2021).

Amongst the most basic methods to be considered are (preliminary) hazard analysis (HA) variants (Dörr and Häring 2008) (Ziehm et al. 2010) (Ziehm and Häring 2011) (Thielsch 2012) (Schäfer, Kopf, and Häring 2014) (Häring 2015a) (Vogelbacher et al. 2016) (Häring 2021b) and system level or system functional level failure modes and effects (FMEA) analysis (Carlson 2012) (Häring 2021a), including related modifications and extensions (Bluvband, Grabov, and Nakar 2004) (David, Idasiak, and Kratz 2008) (Häring et al. 2025).

However, the ambition of the present work is the feasibility assessment of system functions only as obtained from design thinking assessing expected key technological challenges. This is less than a preliminary hazard analysis of a system concept or a functional FMEA on system level resorting to a design concept.

The aim is to assess a system concept idea based on system functions from design thinking deemed sufficient specific to select actual technologies and deciding on the expected development effort to a given technology development level (TRL), e.g. TRL 5-6.

The expected results of the approach can be seen as input for further nested more detailed tabular system-performance driven assessments as used in (Fehling-Kaschek et al. 2019) (Häring, and Fehling-Kaschek et al. 2021) (Häring, and Schäfer et al. 2021), or for procedural experts-based assessments, e.g. as proposed in (Rehak et al. 2023) (Rehak et al. 2025).

The remainder of the paper is structured as follows. In section 2 the methodology is presented. It consists of a tabular scheme for key system functions as line-entries with flexible 'columns' covering their (i) objectives at system level, (ii) measurement of achievement of system function aims, (iii) expected challenges and advancements beyond state of the art, and (iv) allocated technologies. This is combined with a free system functional drawing that roughly aligns the functions along a typical interaction of the approach with end user roles.

Section 3 provides a sample table when applying the approach to a person identification system that uses the capabilities of modern smartphones in a minimalistic but sufficient way to allow a walk-through, drive-through and short stop experience person identification as traveler pedestrians, in individual traffic vehicles, or in buses, respectively.

Section 4 provides a summary, conclusions and possible extensions of the approach. Focus is on minimum requirements of the approach to enable joint functional design thinking understanding, sufficient for an assessment of the expected necessary development resources.

2. Methodology: Description of Graphical Representation Interlinked with Tabular Function List

Methodology requires to provide a list with key system functions in a single graph with short narratives what the system function do in all the application cases. Besides a verbose description, each system reliability function should also be graphically represented. Narratives should interlink as many as possible functions to represent interdependencies, formulated in an active way.

Tabular listing is proposed for flexibility with one line per system function, which is further divided using bold face headings, which enables compact but very structured representation. Numbering in system function graphic and table should be identical and be sorted as much as possible according to a typical system interaction sequence.

Resolution of system functions should be approximately identical by using for comparison system development resources expected, operational resources, subsystem costs, complexity of functions, and/or relevancy of processes covered for overall solution.

Subsystems or system-functions are proposed to be graphically represented, possibly resorting to real-world images of similar systems to ensure direct understanding. For each system function a representative abstract symbol is proposed to be provided for summarizing visualization and enabling context association.

For visualization and representation of expected issues during system development, semi-quantitative labels could be used for the tabular evaluation. Overall scores with some refinement could then be used within the graphical representation, e.g. traffic light colours.

Minimum consistency requirements include: Each system function should be assessed as in principle feasible within a realistic development time, and all categories should be filled out to ensure comparable level of system functional assessment. The resources needed and the expected challenges during development are proposed to be approximately equal. However, this does not exclude the option that the tabular representation only covers system functions that pose significant challenges, whereas the schematic needs to cover always sufficient system functions to describe the system context.

3. Example and Discussion: Smartphone-Enabled Walk- and Drive-Through and Short-Bus-Stop Border Control

Figure 1 describes the sample system in terms of its main smart objectives and related functions SO1 to SO7. For instance, airport traveler pre-registers with digital identity in extended digital wallet in smartphone, including test digital identity document verification, biometric face and fingerprint recognition. At the border, person activates extended wallet app consenting in border crossing while smartphone secure wallet is located and identified using ultrasound. Passenger presence is confirmed using heartbeat identification. In addition, a remote camera system does a recording of the person during walk-through. On-the-move the person takes

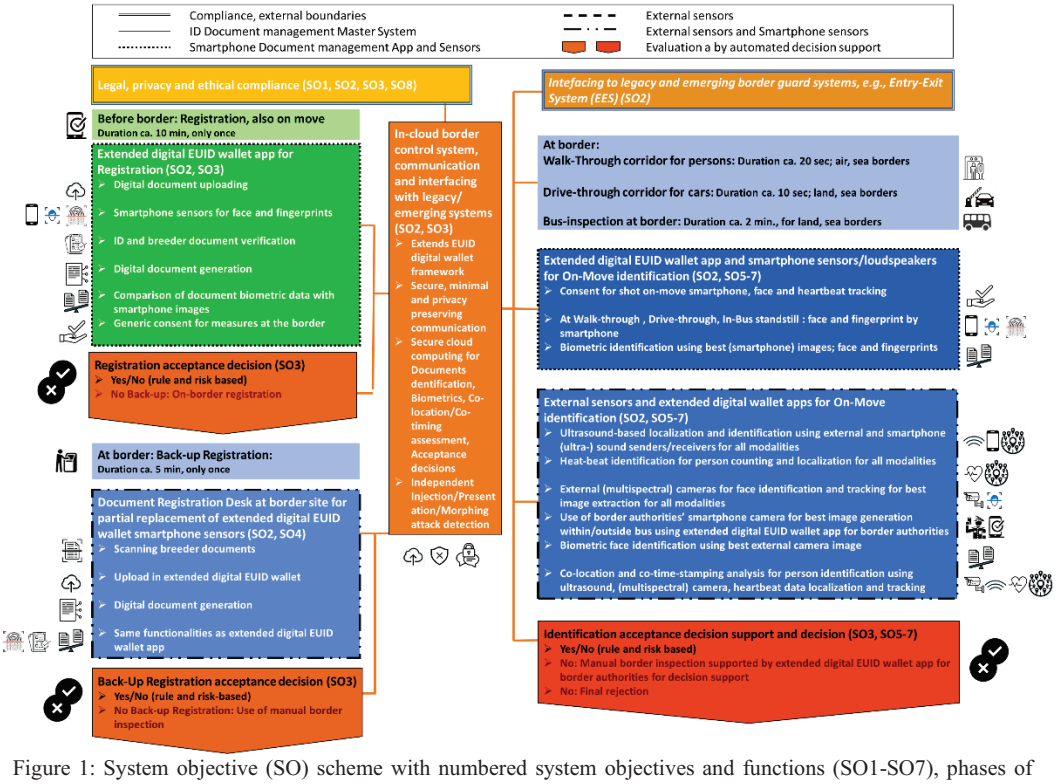


Figure 1: System objective (SO) scheme with numbered system objectives and functions (SO1-SO7), phases of identity document management, person identification and related capabilities on abstract level.

Table 1: Example of system function floating tabular description for walk-through person identification, focusing on identification of digital wallet on smartphone and its localization. Categories are given in flexible floating columns that adopt to text length and are color-coded for fast visual identification: Smart system objectives (**SO**, red), related key performance indicators (**KPI**, orange), related state of the art and challenges addressed (**SotA&C**, blue), and solution step details (**S**, green).

SO: SO5: Walk-through person identification within ca. 30 sec. This includes: SO5.2: Smartphone digital EUID wallet identification, localization and tracking limited in space and time during walk-through on lane using speakers and microphone in ultrasound range, while persons are being recorded with external cameras and are taking few images of their faces and fingerprints. **KPI:** Includes KPI5.7.1: Assessment that obtained position time histories of ultrasound localizations fit together using external camera system data and time and position stamps of images taken with smartphone considering: (i) Physiological spatial (e.g. arm-length) and reaction time constraints (e.g. time-distances between images); (ii) Logical sequence of events; (iii) Feedback of traveler to supporting advice given by extended digital EUID wallet app. **SotA&C:** The current state of smartphone localization is well-developed, particularly in indoor environments, where technologies like Bluetooth, Wi-Fi, ultra-wideband (UWB), and acoustic localization are widely used (Fischer et al. 2022). Of these, only UWB and acoustic localization achieve high accuracy, with precision below 10 cm. A significant challenge, however, lies in compatibility, as UWB is only available in a limited number of recent devices, complicating its deployment across a wide range of smartphones (Hoflinger et al. 2012) (Ens et al. 2015) (Hoppe et al. 2015). Acoustic or ultrasonic localization technology presents a favorable balance between accuracy and compatibility, as most modern smartphones can emit signals in inaudible range. However, time difference of arrival (TDoA) based systems can be challenging to set up and maintain. Acoustic arrays, on the other hand, allow for a reduction in the number of required fixed anchor nodes simplifying deployment (Fischer 2024). **S:** Innovative Solution Step (S11): Ultrasound localization of smartphone digital wallets for all modalities and border types using speaker, microphones and well-placed external tags for all modalities and border types. This functionality will utilize acoustic array technology to develop a smartphone-based acoustic localization system that achieves state-of-the-art accuracy of under 10 cm while requiring a minimal number of anchor nodes (two or fewer). Additionally, the system is designed to support simultaneous signal emission from multiple smartphones by employing advanced array signal processing algorithms, such as sparse arrays, to enhance performance and accuracy in multi-device environments.

selfie and fingerprint images using the smartphone. All information is used to validate or reject person identity by comparing biometric data of face and fingerprints with ID-document data, as well as by assessing logical and time consistency of measurements using camera data and ultrasound localization data. Please refer to Figure 1 for further details of the identification process.

In Figure 1, also phases are added to structure the functional interaction of the system with its users, covering preregistration, back-up registration at border control sites, and finally on-the-move identification. Decision points in the in-consent identification process are provided, including back-up standard identification. Similar functions use similar color coding, box line types indicate type of capability, and icons visualize the functional activity.

Figure 1 covers in total 7 SO functions, mainly in sequence how they are employed in logic order when identifying a person. Note that some functions are employed repeatedly in modifications only, which is indicated by their numbering hinting at subfunctions. There is no criticality ranking of system functions provided in Figure 1, as prosed in section 2.

Already the sample entry of Table 1 refers to a sample system function solution of number S11, i.e., the allocation of the smart system functions might require more technical functions, similar as mentioned in the introduction section 1.

Table 1 lists (i) tabular information for the top level system smart system objective **SO5** on person identification, in particular identification and localization of the wallet on the smartphone using ultrasound for directional triangulation as well as for secure identity data identification. Related (ii) key performance indicators (**KPI**) include consistency of localization with camera data as well as consistency of images of

smartphone with positioning, including that their time stamps fit to the trajectory of the moving person. Related (iii) state of the art and challenges addressed (**SotA&C**) cover fast self-calibration of localization system to different smartphones with different ultrasound senders/receivers, which are standard sound speakers and receivers of smartphones used out of range. (iv) Solution step details (**S**) comprise the selection of array ultrasound receivers and senders along the walk-through area to optimize localization with a minimum set of tags. Table 1 references to literature, mainly in SotA&C and S columns.

Table 1 reveals that system function challenges and innovation gaps addressed are assessed as different. The systemic function is technologically challenging as it requires successfully applying an already proven self-calibrating ultrasound localization approach to representative heterogenous smartphone devices.

Figure 1 shows that standard functions are hardly resolved, e.g., energy supply or support by human resources. Also that the sorting of the SOs is not linear, indicating the difficulty to provide a representative flow of events throughout.

4. Conclusions and Outlook

The paper provided a minimum framework to understand system functions using an all use case visualization schematic with numbered top-level system functional verbose objectives (SO). Based on this system understanding, it was shown that an expert group is capable to of identifying key technology challenges and technology gaps to be addressed sufficiently to estimate further development efforts. Interlinking was provided by numbering functions and through graphic formal vicinity.

It was found that instead of system function presentation, system function objective presentation (SO) is key as well as related key performance indicators (KPIs). Based on this systemic understanding and context, state of the art gaps and gaps (SotA&G) can be identified which allow for a final system function definition and description. This approach allows to first formalize design thinking in terms of system level functions, before identifying research and technology gaps informing the final technology selection of solution (S) steps.

The approach is flexible, because of its limited effort but experienced efficiency as well as its minimum consistency requirements set (see section 2). At the same time, it is flexible below the system functional level, e.g., the same KPIs can be asked to be fulfilled by different system functional objectives (SOs), as well as the same technological solutions functions (Ss) can be allocated to the same system functional objectives (SOs).

In practice, the system functional schematic and the related tabular explanation are iterated till convergence regarding system context understanding, system boundary identification, system function identification and partitioning, KPI refinement, understanding science and technology gaps and function allocation, to achieve the most promising technological function selections.

Further work could update the described systemic functional design assessment and technology selection approach in later development phases. For instance, based on the design concept, comparing the envisioned with the actual challenges, assessed in terms of the provided KPIs as well as with system analytics methods as listed in the introduction. Expectation is that this might support the identification of further minimum consistency requirements as well as streamline the proposed approach.

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