Taylor & Francis
Taylor & Francis Group

Behaviour & Information Technology

ISSN: 0144-929X (Print) 1362-3001 (Online) Journal homepage: http://www.tandfonline.com/loi/tbit20

Cognitive work analysis in the conceptual design of first-of-a-kind systems – designing urban air traffic management

Jonas Lundberg, Mattias Arvola, Carl Westin, Stefan Holmlid, Mathias Nordvall & Billy Josefsson

To cite this article: Jonas Lundberg, Mattias Arvola, Carl Westin, Stefan Holmlid, Mathias Nordvall & Billy Josefsson (2018) Cognitive work analysis in the conceptual design of first-of-a-kind systems – designing urban air traffic management, Behaviour & Information Technology, 37:9, 904-925, DOI: 10.1080/0144929X.2018.1505951

To link to this article: https://doi.org/10.1080/0144929X.2018.1505951

Published online: 08 Sep 2018.

BEHAVIOUR & INFORMATION TECHNOLOGY
2018, VOL. 37, NO. 9, 904–925
https://doi.org/10.1080/0144929X.2018.1505951

Cognitive work analysis in the conceptual design of first-of-a-kind systems – designing urban air traffic management

Jonas Lundberg [a], Mattias Arvola[b], Carl Westin[a], Stefan Holmlid[b], Mathias Nordvall[b] and Billy Josefsson[c]

[a]Department of Science and Technology, Linköping University, Norrköping, Sweden; [b]Department of Computer and Information Science, Linköping University, Linköping, Sweden; [c]LFV, Norrköping, Sweden

ABSTRACT
Cognitive Work Analysis (CWA) is an appropriate approach in design for high-stakes domains, such as air traffic management (ATM) since it focuses on human expert performance in regular and contingency situations. However, CWA is not suitable for the design of a first-of-a-kind system since there is nothing to analyse before the start of the design process. In 2017, unmanned air traffic management (UTM) for intense drone traffic in cities was such a system. Making things worse, the UTM system has to be in place before the traffic, since it provides basic safety. In this research-through-design study, we present conceptual designing as a bootstrapping approach to CWA in the design of a first-of-a-kind UTM system. In a series of co-design workshops, we identified future services, traffic patterns, and regulations that framed the design of UTM system concepts. They were based on combinations of four basic building blocks: points, lines, planes, and volumes. Concepts of point-based control, airport geofences, grid squares, layers, and tubes were discussed. Throughout the conceptual designing, results were documented in an evolving Work Domain Analysis (WDA), which is a cornerstone of CWA. This approach allowed us to bootstrap the CWA for a first-of-a-kind-system.

ARTICLE HISTORY
Received 17 June 2018
Accepted 16 July 2018

KEYWORDS
Cognitive work analysis; conceptual designing; service design; work domain analysis; unmanned aircraft traffic management

1. Introduction: design of unmanned traffic management, a first-of-a-kind system

One of the most riveting technology changes in aerospace is the introduction and application of unmanned aircraft systems (UAS) and remotely piloted air systems (RPAS) commonly referred to as drones. The potential applications of drones and their usefulness are many, including search and rescue, surveillance, public safety, package delivery, entertainment, and not yet identified uses.

The largest foreseen development and utilisation of drones will be at low levels with the highest demands growing in urban environments and cities (SESAR Joint Undertaking 2018). This inevitably increases risk. To that end, a considerable challenge lies in how to manage the massive influx of drones, particularly in close proximity to humans and in proximity to exiting air traffic.

Drone usage can be seen as ‘missions’ (e.g. package delivery, surveillance, search-and-rescue). Missions, whether independent, cooperating, or competing, in the same or nearby airspace results in traffic, with potential interactions between drones or with other missions. The design of an Unmanned and Urban Air Traffic Management (UTM[1]) system for intense drone/unmanned traffic in cities is particularly challenging since the process itself (i.e. the drones, the missions, and the traffic at forecasted levels) does not yet exist. This airspace is currently, in 2018, uncontrolled.[2] Traffic (e.g. helicopters, small aircraft) in uncontrolled airspace follow rules and regulations, but the traffic (e.g. positions, movements) is not monitored in real time.

Cognitive Work Analysis (CWA) is an approach well suited for modelling of complex sociotechnical systems, to address system design challenges in high-stakes domains, such as Air Traffic Management (ATM). By systematically considering the constraints that affect behaviour (but not specifying behaviour) CWA supports constructive and effective performance/problem-solving in both anticipated (regular) situations and unanticipated (emergency) situations (Vicente 1999).

These characteristics are particularly important in systems that must be ‘monitorable’ and controllable, where humans are accountable and responsible regardless of automation level; including autonomous system operations. However, with first-of-a-kind system, the CWA analyst is left in a tricky situation, since the basis for making an analysis is weak (Naikar et al. 2003). In a worst-case scenario there is neither a current system nor any current work practices to analyse.

CONTACT Jonas Lundberg jonas.lundberg@liu.se

A regular CWA would have to start with the current situation and systems for ATM, and apply iterative design to transform it. However, a disruptive technology like UAS on a massive scale, would give rise to completely new conditions for work that operate on a different set of assumptions and with a different control problem. As technology changes radically, tasks also change radically, which give rise to radically new needs and requirements (Carroll and Rosson 1992). CWA is like traditional user-centred design approaches a kind of hill-climbing process, which is well suited for incremental innovation but not for the kind of radical innovation that happens during disruptive technology change (Norman and Verganti 2014). What is needed instead is a kind of *conceptual designing*, involving framing and re-framing to produce radically new designs to fulfil current goals in new ways, or aim to discover radically new purposes (Dorst 2015; Ylirisku et al. 2016). In conceptual designing, the projection of what-if-scenarios is used to frame the design effort.

The overarching purpose of this paper is to develop knowledge about design methods for a first-of-a-kind system. We will explore a combination of cognitive work analysis and conceptual designing in which we use the unmanned and urban air traffic management design project as a case study to reflect on how this combination of methods works. The research approach for this methodological work is research-through-design. The research result is a description of and a reflection on the design project. This includes describing what was done (the design process) as well as what happened (the design product). The discussion is a reflection on how it went, and the lessons that we can learn from that.

The scenarios for unmanned urban air traffic management that we explore along the way, the proposed services, and the foreseen traffic patterns, are accordingly instrumental to the discussion of how to use a combination of cognitive work analysis and conceptual designing to design first-of-a-kind systems.

1.1. Unmanned urban air traffic management

The main purpose of UTM is to facilitate the safety and efficiency of drone traffic operations and manage airspace usage, considering relevant information (e.g. drone positions, obstacles, restricted zones, drone identities) beyond visual line-of-sight from drone operators on the ground. Oher aspects that may be included for consideration are e.g. efficiency of the airspace, fairness of airspace usage. Other concerns are for instance: (a) to keep the traffic inside or outside of designated areas; (b) with more intense traffic, some principle of airspace organisation must be enforced (i.e. an airspace design, traffic rules); (c) violations of these principles must also be managed (as well as contingencies such as drone failure).

In both Europe and USA, UTM, development is outlined as stages of research and development with increasing aspects of risk (e.g. traffic over populated areas), complexity of traffic, and potential for services (Prevot et al. 2016; SESAR Joint Undertaking 2017). Cities, the most complex and important (SESAR Joint Undertaking 2018) stage, is placed at the end of the research and development chain. UTM, at least initially, is not completely separate from ATM, but needs to be integrated (SESAR Joint Undertaking 2015). In cities, an important point where UTM and ATM meet is around local airports. The need for inclusion and coordination with currently existing types of air traffic (e.g. helicopters, small aircraft) is a concern.

What the core principles of control and management are going to be, or could be, for the design of future UTM systems is of major importance. Several perspectives can be taken. Firstly, conventional Air Traffic Management (ATM) must be considered. The main principle in ATM in controlled airspace is point-based control. It means that each aircraft is monitored individually, for conflicts. Predictive tools are also (in some places) used to look-ahead, and to warn for imminent conflicts. It might seem at first glance like this principle could also be used for UTM considering that it is a solution for managing air traffic. However, recent approximations indicate clearly that ATM concepts will not scale up to UTM. One recent estimate from the U.S. is that UTM (using ATM concepts) could require 35 times the current ATM work force (Dao et al. 2018) already in 2020. The Metropolis project (Sunil et al. 2015) used future population estimates to judge how traffic levels may increase in the future. A city the size of Paris was modelled as a baseline for the project. To account for city growth until 2050, four population sizes of 14, 18, 22, and 26 million people, respectively were considered. By 2050, 4% of the population was foreseen to use Personal Aerial Vehicles (PAV), while a per capita demand for Unmanned Aerial Vehicles (UAV) deliveries was set at 5.5 packages per annum. It is therefore probably not viable to use ATM solutions as-is for UTM as well. UTM for high-density, high-volume drone traffic in the skies of European cities requires radically different solutions than those currently in use in ATM. Although, highly automated ATM concepts have been evaluated before (Prevot et al. 2011), new ways of displaying large amounts of information will be required for UTM traffic in cities (Prevot, Homola, and Mercer 2016).

Secondly, there are currently emerging concepts and solutions for countryside UTM (Battiste et al. 2016).

The main principle is to *separate traffic into different volumes*, for the duration of each mission, or for segments of each mission. Basic solutions such as beyond-line-of-sight operations, and separation of traffic by reserving separate airspace blocks for different users have been tested (Johnson et al. 2017). However, city UTM is different compared to this context regarding complexity, congestion, the need to share air space, and risks to human safety below the drone missions.

Thirdly, previous research has addressed UTM for cities. The Metropolis project (Sunil et al. 2015) approached UTM from the perspective of airspace elements, e.g. division into zones, division into layers, and tube networks. Simulated traffic was used to evaluate those elements against performance metrics such as capacity, complexity, safety, and efficiency. Specific metrics have also been addressed, e.g. airspace capacity (Bulusu et al. 2017) and noise (Bulusu, Sedov, and Polishchuk 2017). Further, the problem of city UTM has also been addressed from a completely different point of view – the point of view of *ownership of airspace* (Foina, Krainer, and Sengupta 2015). The airspace over the city was divided into air parcels, based on land owners in the city (e.g. with the city owning air over the roads). This introduces the need to take rules of passage of each parcel into account for route planning.

Regarding the degree of automation and human involvement in UTM, the Metropolis project evaluated *fully autonomous* drone traffic (Sunil et al. 2015). It is an approach that stands in stark contrast to the manual monitoring of aircraft in ATM. However, even though UTM may go toward autonomy (i.e. self-governance), current values held by airspace stakeholders imply that UTM requires human responsibility and accountability. For instance, airspace users have stated that 'any future UTM system should be centred around the needs of its human operators by providing an automated setting that enables a human-in-the-loop system supporting the user as much as possible' (Eurocontrol 2017).

2. From work domain analysis to conceptual designing

When we approached the conceptual design of UTM for cities, we started with Cognitive Work Analysis. It is an approach that contains several analytical activities, see e.g. (Jiancaro, Jamieson, and Mihailidis 2014). In this paper, we will focus on the first activity of Cognitive Work Analysis; the work domain analysis (WDA). The purpose of WDA is to describe system constraints, which define the freedom and possibilities for action in control tasks. WDA structures constraints in a hierarchy from physical objects to overarching purposes, highlighting dependencies and process boundaries.

WDA focuses on a process that should be constrained and controlled (e.g. nuclear power generation, air traffic). Within those processes, WDA supports management of both regular and unanticipated situations. WDA does, however, not extend to new unanticipated processes. For UTM, this concerns processes that emerge from traffic interactions emergent from and generated by different missions, within system constraints. To generate a rich view on future situations, and (traffic) processes that could occur in them, as well as defining them in terms of control systems/tasks, is an important goal when working on WDA for systems that do not yet exist. Further, overarching system goals must be defined (surely similar to other air traffic control domains, but not necessarily identical). Also, options for human involvement must be identified, e.g. based on process characteristics and control system options. These aspects are not currently defined for UTM, and the processes, control systems and operator tasks do not exist (thus cannot be used as a basis for analysis).

To counter this shortcoming (when designing first-of-a-kind systems) of WDA, we make use of conceptual designing. Conceptual design fosters radical innovation by focusing not only on how something should be designed, but also what it is that should be designed (Ylirisku et al. 2016). Sketches, prototypes, and design fictions project desirable, unwanted, possible and impossible future situations. They become available for exploration of not only solutions to the problems of today, but also exploration of opportunities for completely new purposes to strive for. We propose that this makes it possible to bootstrap a cognitive work analysis. The conceptual design process is divergent, which means that every sketch, prototype, or design fiction contributes with a re-framing with new consequences. Accordingly, the framing of potential future situations makes it possible to bootstrap the design process by making strategic assumptions. The framing effectively implies overarching situations and contexts, core processes, intentional constraints, such as the rules of air, airspace structures etc. Some aspects of the future system that are known can be used as a starting point, based on which some constraints can be determined. This is particularly true for causal constraints relating to the physical environment (e.g. city topography, buildings, roads, drone sizes, weather) and drone properties (e.g. flying characteristics and aerodynamics of drones). However, other aspects central to UTM are currently unknown or under development, such as constraints that stem from social laws, values, or conventions. Finally, the future usage of drones, that will result in traffic (the process to manage), is only partially known. In our work, to identify processes to analyse, we use situations as the starting point. We ask the question, what (physical) processes occur here, what values (e.g. safety) are central? The central idea is for conceptual design to take the situation as the point of departure. The idea is to design systems for particular situations, but to go through several situations during design work. This level is thus outside of the system, which (like in previous work) starts at the level of functional purposes. To complement the WDA for conceptual designing, an additional overarching constraint level was therefore added:

- Situations (S) and *framing of situations*. The overarching situations and the processes (e.g. traffic) within, constitute a basis for formulating the functional purposes of the system (next level). The framing of the problem (e.g. an airspace design problem, regulation, ownership of airspace, traffic patterns), constitute different views of situations, of processes and their contexts.

We also used five levels of WDA that are common in the literature (Rasmussen 1986, 20, 55; Naikar 2009, 2017), including air traffic management (Xiao et al. 2008), to describe both aspects/functions of the system/process and of supervisory control (Rasmussen 1986).

- Functional purposes (FP). This level describes why the system exists (what it does, what effect it has on the environment). Descriptions on this CWA level often focus on external core constraints (e.g. safety) that the system should provide. From the perspective of *supervisory control*, it is an *external task*, i.e. a shared purpose and aim which is not controlled, but adhered to.
- Abstract functions (AF). This level describes the system functions (e.g. energy balance), and *supervisory decision tasks* (e.g. plan, prioritise) in abstract terms. If known, processes can be described in terms of algorithms (for instance based on physics) or as value and priority measures for control (e.g. to calculate safety, readiness).
- Generalised (purpose related) functions (F). A pattern/generalised function (e.g. power supply, threat identification) and *supervisory information process* (e.g. search) that can be applied and instantiated by particular implementations.
- Physical functions (PF). It describes physical (object) processes and characteristics (e.g. capabilities and limitations) It also describes the *implementation of supervisory functions* (e.g. by humans or by automation).

Table 1. Initial work domain analysis.

Level	A to B	Inside area
S	Drone needs to fly from A to B	Drone(s) needs to operate in specific area
FP	Some known overarching objectives, e.g. safety, efficiency	
AF	Generic efficiency metrics, e.g. regarding path lengths, safety metrics (e.g. infringements)	Generic volume capacity metrics
F	Monitor current drone position, versus other airspace objects	Monitor current drone position, versus 3d boundary (airspace constraints) locations
PF	E.g. LIDAR detection capabilities	E.g. GPS accuracy (limitation)
O	e.g. drones, buildings, 'inside area' also has a 'virtual boundary' object	

- Objects and attributes (O). The objects included in the system, and their attributes (e.g. size, shape, weight, location). This includes physical objects such as drones, but also 'virtual objects' (e.g. the location of a 'virtual boundary' in Table 1) that are metaphors for different kinds of constraints to impose on the air space (through control). It also includes *interface objects in the supervisory control system* for the operator.

Some previous work on CWA has addressed novel systems (Naikar et al. 2003; Pejtersen and Rasmussen 2004). For example, (Naikar et al. 2003), approached a new kind of radar system. Although their radar system had not yet been built, there was a conceptual design to use as a starting point for team design. In our UTM case, there is no reasonably complete existing conceptual design either, and this meant that we had to make also the conceptual design while conducting the WDA in parallel. In the next section, we will describe the WDA as we used as a starting point.

2.1. An initial work domain analysis

The WDA starts with some known basic situations and functions. We exemplify (Table 1) with some characteristics of individual drone missions, such as basic direct flights from A to B (deliveries) and drones that work in a specific area (e.g. area surveillance, drone play area). Here, we work toward adding contextual complexities of a city. First drone-based services, then regulatory concerns, setting the stage for designing UTM concepts.

3. Method: research-through-design

A research-through-design approach was used, which means that design activities play a formative role in the development of knowledge (Stappers and Giaccardi n.d.). In the present study, the design work is embedded within a research process that is similar to a case study (e.g. Creswell 2013). The design work in our project is done to produce appropriate solutions to improve projected UTM situations. Design artefacts in the forms of visions, sketches and prototypes are created during the design process, and are central to the knowledge making process, but produced design artefacts are instrumental to the research work. The research work takes the described design work as an object of analysis and aims to produce knowledge about the combination of WDA and conceptual designing that can be used by others who aim to make a first-of-a-kind systems design. The explored design solutions can however also be considered a novel and relevant knowledge contribution that is valuable for other designers of traffic management systems of different kinds, but a thorough analysis of the design space of such solutions are beyond the scope of the present article.

The aim of the design project was to both shed light on the traffic (the core process) and to explore basic building blocks (virtual objects) and the composition of UTM functions. First, services that drones can provide in cities were envisioned in a half-day workshop. Based on these services, core traffic patterns were identified by the research team. In a second half-day workshop with regulators considered implications for 'rules of the road' based on the vision of UTM traffic derived from the first workshop. The goal of the first two workshops was to establish an initial context of traffic (the process) and overarching regulatory value and priority measures for city UTM. Finally, a workshop (lunch-to-lunch) involved four ATM experts (air traffic controllers, drone safety experts), who discussed and evaluated future UTM concepts. In terms of the WDA, this part of the design work is top-down, focussing initially on situations, functional purposes, and abstract functions, progressing toward functions/patterns, and physical functions.

In parallel with the workshop series, UTM 'building blocks' were designed by the research team, to be used in workshop three as a starting point. Also, an interactive traffic simulation and visualisation were developed incrementally. Both works with 'building blocks', lo-fi materials and the visualisation and simulation are a bottom-up approach, to work at the functions, physical functions and objects level in the WDA, to understand particular situations, and to analyse consequences for higher levels of the WDA.

In workshop 1, the visualisation only contained the map, and was only used to prepare workshop materials. In Workshop 2, it contained low-density traffic between logistics hubs, and was at the centre of discussions. In workshop 3, it also visualised how drones may automatically detect-and-avoid, giving the participants an impression of what the traffic situation could look like. However, the hands-on design work was primarily based on use of lo-fi materials. After workshop 3, we refined and prototyped concepts based on the output of workshop three and analysed the outcome.

4. The case: Norrköping city

To make the design work more tangible and focused, we decided to base it on a specific city, Norrköping, Sweden, with 140,000 inhabitants. This city was characterised by relatively low buildings (not reaching up to the 'en-route' A to B part of drone missions), and a central airport with a few departing and arriving flights per day.

5. Workshop 1: services and traffic patterns

In the first workshop, the focus was on developing ideas and concepts of services supported by drones, since the character of high-volume traffic will depend on the reasons for which the drones are in the air, and how those reasons create patterns of traffic. The concept designs were in later stages to be used to show archetype services (Holmlid and Blomkvist 2014). The nine participants had backgrounds in design, service development, and technology-driven innovation. The workshop was run in five steps, (1) individual idea generation, (2) sharing all ideas, (3) a sub-group exercise where ideas were turned into service solutions, (4) sharing solutions, (5) in sub-groups making a storyboard of one service concept. In all steps but the last, the participants were directed to work on services within the areas of transportation, sharing, smart city and entertainment. In total there was identified 140 potential drone-supported services (Figure 1).

Based on the service concepts, and the scenarios for those concepts, basic traffic patterns were identified, that drive the development and shift of overarching traffic patterns, over the course of daily (Figure 2), weekly and yearly rhythms.

Regarding volume, using the same estimation of traffic as in Metropolis (Sunil et al. 2015), citizens in the city of Norrköping (with the current population) would on average have 5.5 package deliveries per person and year by drone, and 4% would be travelling by drone. If all transports occur during daytime (12 hours), that results in, 174 package deliveries per hour, and 1 personal drone transport per hour. In our scenarios, we do not look as far ahead in time regarding drone technology but assume a basic delivery drone (2 kg cargo capacity, 5 kg weight, and a range of 30 min/15 km).

One of the traffic patterns were *commercial or public recurring operations* (e.g. daily business deliveries in the morning, food court deliveries around lunch time) that can be planned for, in volume as well as in timing. Some will depend on multimodal transportation

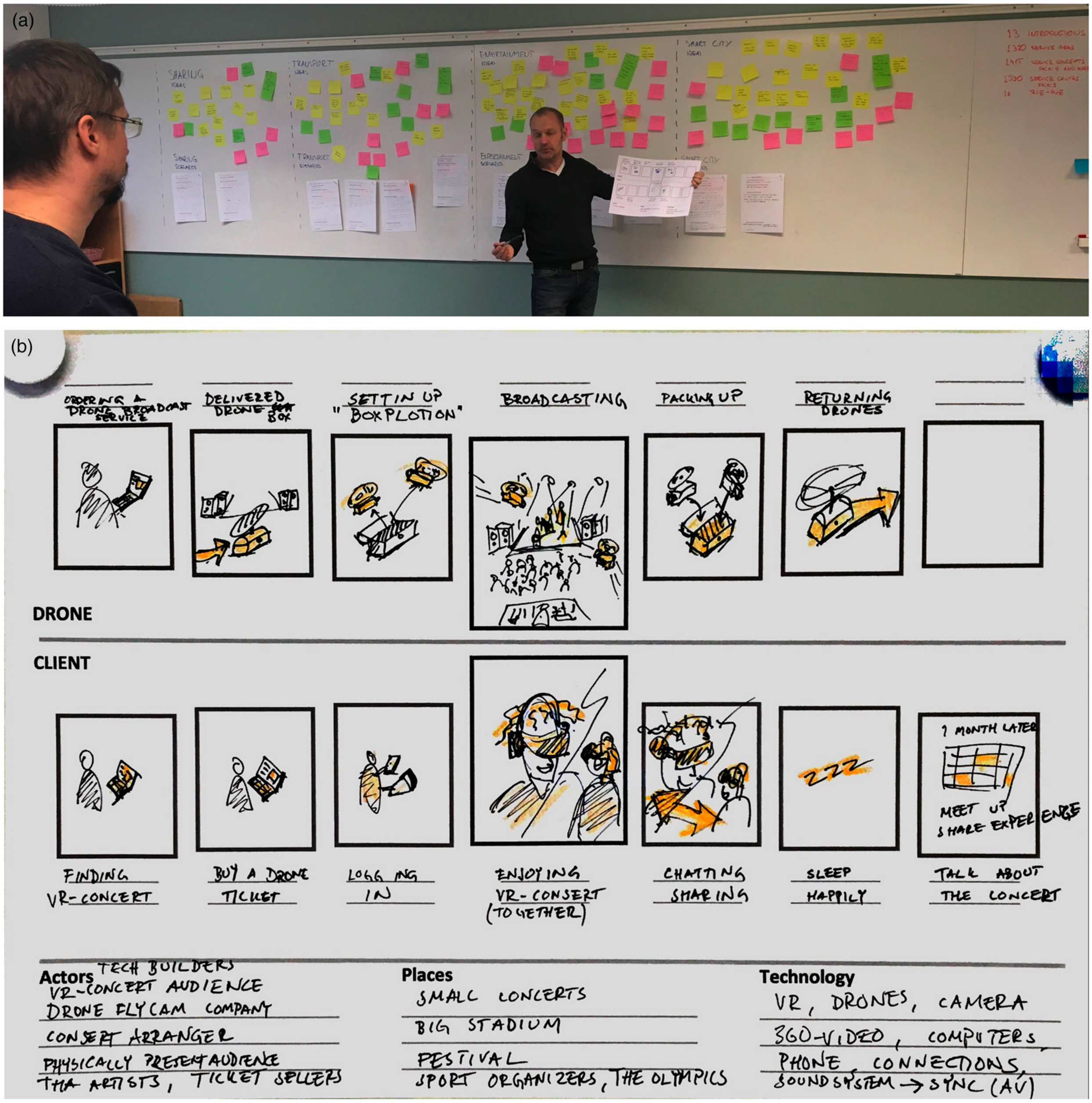

Figure 1. (a) the collection of ideas, (b) a service concept example.

solutions, e.g. a hospital delivery originating from the city airport. They are also characterised by being defined by service level agreements between actors, such as 1-hour delivery schemes. Some patterns are likely to be planned a long time ahead, following reoccurring schedules (regular traffic), while the number of ad hoc, short-term planning, services will grow, and represents a big difference from the more generally regular traffic patterns in ATM.

Another basic traffic pattern is *peer-initiated operations* (e.g. private sharing of items between friends, by drone). These are characterised by dependence on time of day combined with area of a city. Some kinds of peer-initiated operations, will mainly happen after-work hours. Some may be tied to a specific event, such as a festival.

The final identified traffic pattern is *high priority irregular operations*. These are characterised by limited possibility to foresee and plan for, but also by having high priority in short-term traffic planning. This can be an emergency hospital transport, police drone operation after a bank robbery, or a surveillance mission caused by a serious incident.

From this, some overarching and tentative process characteristics can be hypothesised and used as a starting point to bootstrap the design process. In our

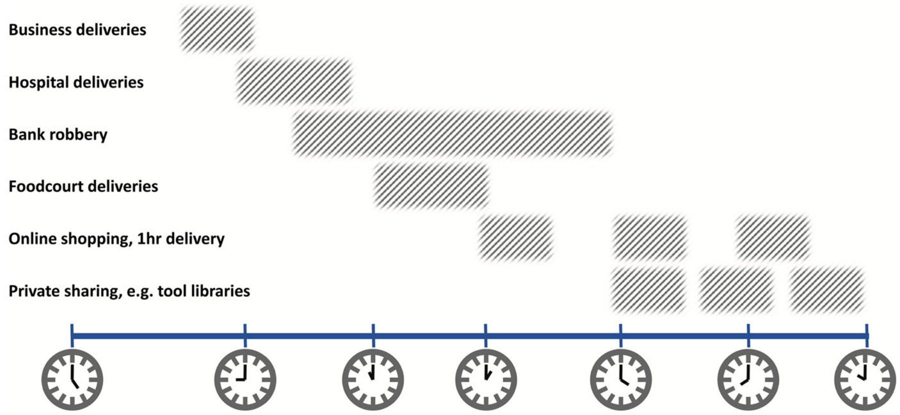

Figure 2. Daily traffic pattern variations.

WDA we can therefore add some overarching items for UTM:

- *Situations:* Overarching service categories: commercial or recurring operations; peer-initiated operations; high priority irregular operations, framing the drones in terms of traffic patterns, or in terms of the business relation between UTM system provider and UTM service users.
- *Physical functions:* Overarching traffic process characteristics: Both high-volume and low-volume traffic periods were identified, as well as traffic with varying planning horizons. Both variations in traffic that have high priority (e.g. emergency services), and traffic pattern variations due to variations in normal-priority services are likely during a day.
- *Generalised functions:* Change airspace design to match traffic variations. Dynamic concepts for structuring traffic may be useful, to match traffic variations over the day.
- *Abstract functions:* Service-dependent priority and value measures: Some of the values and constraints will regard service quality (e.g. one-hour delivery should take one-hour maximum; emergency services must be given priority). These service-related constraints and values may vary in the system, depending on what services are delivered. Depending on the importance of these factors, providing e.g. service quality could become part of the functional purpose of the system.

6. Workshop 2: regulation

The six participants in our three-hour workshop on regulation were experts on ATM, Swedish and international drone regulation, and city safety/security. The focus was on future regulation, for intense high-volume traffic in cities (thus, not on current regulation). In the workshop, participants examined and discussed both overarching national and international UTM regulation (based on the context derived from the first workshop), and city traffic. The discussion was centred around our 3D traffic visualisation. The visualisation at this stage consisted of a map with some basic drone traffic patterns on a touch-table (Figure 4(a)). Further, participants also discussed traffic scenarios for city services (e.g. monitoring of snow status of winter roads).

The overarching issue in the workshop was drone flight reliability, in particular ascertaining that drones do no crash, or that they crash in areas where risk to human lives is minimised. The main take-away for basic UTM regulation for our WDA was:

- *Situations:* Emergency landings and crash behaviour (contingency management) was a critical concern, framing the drones as a safety threat.
- *Functional purposes*: provide safety
- *Physical functions:* Discussions centred on whether it would be better for drones to crash land on houses, or on roads (in the midst of traffic).
- *Generalised functions*: Monitor drone performance limits.
- *Physical functions*: To be allowed in the city, the UTM system should ensure that individual drones are reliable within their performance limits.
- *Generalised functions*: Monitor conditions (versus drone performance limits).
- *Physical functions*: The UTM system should ensure that the performance limits are not exceeded due to variations in environmental conditions (weather) or traffic (congestion).

These regulatory concerns set the stage for the next step of our first iteration of city UTM concept development.

7. System concept design: UTM building blocks

To design basic tentative UTM concepts, several internal design workshops were conducted. Based on previous literature and information on drone traffic in media, basic UTM building blocks for managing intense high-volume unmanned traffic were identified. We attempted to make them as simple (basic) as possible, so that they could be combined into more advanced concepts. Each block combines both a shape to use in airspace design and a tentative view on properties when used to control and monitor traffic. Concepts that differ (e.g. by adding or relaxing some constraint), but have (approximately) the same properties for monitoring and control are considered variations of the same concept. Note that airspace structure is not a question of centralised versus decentralised control. UTM can still be decentralised although incorporating a highly structured airspace. As such, building blocks represent artefacts of a structured UTM.

8. Unstructured traffic (free flight)

UTM can be based on free uncontrolled flight, referred to as 'full mix' in the Metropolis project (Sunil et al. 2015). In this concept, traffic is allowed to go directly from A to B (or fly around in A), without restrictions, self-separating when needed. Note that UTM for an airspace volume might still need to restrict flights to approved operators and require drone identification, and to manage other requirements that do not concern the airspace structure. However, a concern with free uncontrolled flight is congestion – that the operational limits of the detect-and-avoid (human- or machine-based) are exceeded. Alternatively, drone spectrum limits (radio communication capacity) of an area may be exceeded. Further, some exclusion volumes (see below) can be expected in a city, increasing the risk of congestion. Unstructured traffic corresponds to a variant of the last UTM building block below; de-centralised point control (self-separation). In terms of CWA, this can be summarised as:

- *Abstract functions:* Generic operational limits and measures such as spectrum (communication bandwidth), limits on detect-and-avoid during congestion, noise limitations.
- *Generalised functions:* Drone identification, separation of drones
- *Physical functions:* E.g. drone self-separation or centralised automated separation of drones, specific limits on detect-and-avoid for particular drones in particular circumstances.

9. UTM building blocks

The four basic building blocks of UTM that were designed initially (as a starting point in workshop 3, see Figure 3) were the point, the line (tube), the plane (layer), and the volume. Here, we also mention the grid, a concept (variation of the volume) suggested by the workshop three participants. Since these are building blocks that can be used for different purposes, to manage different values, we start

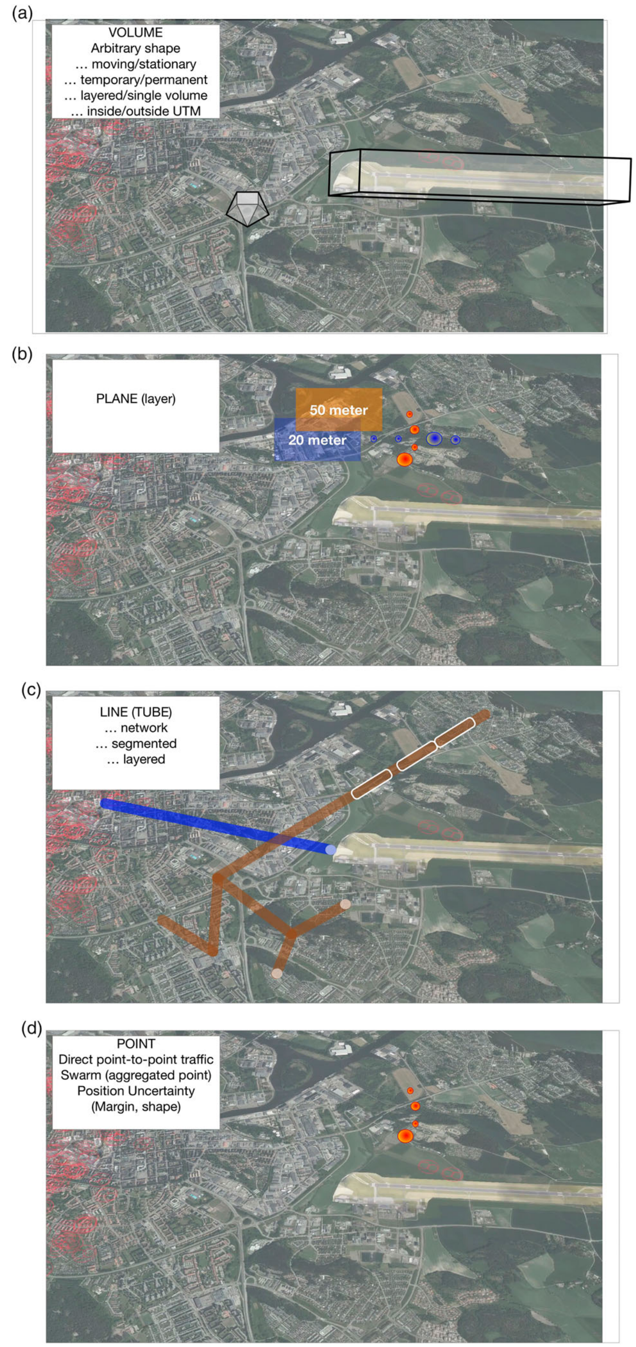

Figure 3: UTM building blocks; (a) volume, (b) layer, (c) tube, (d) point. Background generated from GSD-Ortofoto25 and GSD-Höjddata, grid 2+ ©Lantmäteriet.

Figure 4. (a) low-density traffic, and (b) high-density traffic. Background generated from GSD-Ortofoto25 and GSD-Höjddata, grid 2+ ©Lantmäteriet.

at the level of generalised functions. We further describe the associated information process that is required for control, but we do not specify how it is achieved (by humans or automation, on the level below).

9.1. Volumes, grids of volumes

We firstly consider the (*stationary*) *volume* enclosing (geocage) or excluding (geofence) traffic in an area of operation. It is an arbitrary 3D shape, such as a cube, a dome or a cylinder. From a traffic monitoring and control perspective, the focus is with the borders of the volume, and of entry/exit from it. Volumes are central to the air parcels concept, enclosing the airspace over properties according to ownership (Foina, Krainer, and Sengupta 2015). Volumes is also an important concept to address the safety issue of workshop one, if the decision would be to prefer crashes on houses. If on the other hand, the decision would be to crash on roads, that could lead to further explorations of the tubes concept.

Taking the idea of 'air parcels' a step further, the whole airspace can be divided into volumes, forming a grid, potentially with new characteristics. Volumes can also have a temporal duration, which means that the volume dimensions, and appearance/disappearance of the volume must be considered versus traffic that already is inside the volume (or that has a planned path through it). More complex volumes can also be layered (see below).

- *Generalised functions:* Encapsulate area, to keep objects inside or outside, without controlling particular movements inside or outside (except their relation to borders). *Information process*: monitor (borders and capacity)
- *Physical functions:* Specific virtual 3D volume (its constraints on traffic, e.g. what kind of traffic can move in our out) realisation of how to manage borders (e.g. enforce borders, controlled border crossings, containment capacity of drones).
- *Objects and attributes:* Arbitrary 3D shape (sometimes surrounding physical objects) restricted by limitations in what 3D shapes the control system can generate. Attributes such as location, size.

9.2. Planes/layers, stacks of layers

A simplified version of the volume is the *plane*. A plane is a 3D volume that has no edges (for practical purposes) and provides altitude-based separation. It can for instance be used to separate flights going in different directions, e.g. east–west, north–south, as in the Metropolis project (Sunil et al. 2015). The main advantage of planes is that traffic is (to an extent) independent at each layer, reducing interactions between drones. The use of several planes can be used to adjust airspace capacity, or to keep different kinds of traffic separated. A core concern when using more than one layer is to manage transitions between and through layers. Another concern is that stacking of layers means that some drones may have to fly at a lower or higher altitude than would otherwise be desirable (e.g. considering energy use). Layers can also be used in combination with volumes, resulting in a layered volume. Layers can also be used in a free-flight scenario (reserving one or several layers for vertical avoidance manoeuvres below or over a horizontal free-flight layer).

- *Generalised functions:* Encapsulate (just like volumes). *Information processes*: manage borders (just like volumes), and passages through the layer, manage restrictions on movement in the layer.
- *Physical functions:* Virtual layer (concerns the borders, constraining movement above or below, and inside). It also concerns passages through the layer (vertical movements), and (potential) restrictions on movement in the layer.
- *Objects and attributes:* Virtual object, layer (with start and end altitude), stack of layers.

9.3. Lines/tubes, segments and networks

A (*trajectory*) *line* or *tube* is characterised by traffic that goes in one or two directions, between two/several points, and the central UTM notion is that traffic is separated by separating the lines It can also be connected to other lines, forming a network. It can be thought of as a line with a safety margin of operations around it, forming a tube. It then shares characteristics with volumes. This is similar to the Tubes concept in the Metropolis project (Sunil et al. 2015). A simple UTM solution could be to reserve an entire tube for the duration of a single mission. This is, however, not very efficient.

Further, fixed and shared use tube networks (the Zones concepts in the Metropolis project (Sunil et al. 2015)) could also be used. However, then traffic inside the tubes must also be managed. Either the tubes must be segmented (reserved for specific drones during specific times), or traffic inside the tubes must be monitored (as points) or be based on self-separation (unstructured traffic). However, the problem of self-separation inside tubes may be simpler than that of self-separation in free flight. This is because admittance to specific tubes may be based on drone performance and technology level. There could for instance, be a high-speed tube for drones with specific separation capabilities and high-speed performance. Different configurations may be based on planning of specific flights or based on regularly occurring patterns during different times of the day.

Some concerns for tubes are: (1), intersections between tubes (crossing traffic), (2) boundaries (flying in and out of tube boundaries), (3), shared use of the tube (network). Note that as soon as the focus starts to shift to monitoring of individual drones, e.g. in relation to line borders, then there is a shift to point-based control.

- *Generalised functions:* Encapsulate trajectory. *Information processes*: Manage traffic by reserving and separating trajectories (whole lines from a–b) or line segments. Separation of lines, or of line segments, by planning and real-time monitoring/adjustments. Focus on the trajectories, not on the traffic inside.
- *Physical functions:* virtual intersections (constraints on movement), segments (spatio-temporal constraints on traffic). Restrictions in the system on, e.g.

functionality for managing tube segments and tube intersections.

- *Objects and attributes:* Virtual object (line or tube), network, location, size, etc.

9.4. Points/volumes

The (*moving*) *point* represents a position in space. For control purposes, it usually is given a safety margin around it. It can for instance represent one drone, or a cloud of drones (then sharing characteristics with volumes). It can be modelled as a sphere, disc, or other 3D shape. For control purposes, its central characteristic is that its movements must be monitored in real-time versus other points. Monitoring can be decentralised (by each point / drone operator, i.e. self-separation, making it an instance of free flight) or centralised (by the traffic management system).

- *Generalised functions:* Encapsulate (potentially moving) points. *Information processes*: Manage traffic by monitoring and separating moving points/volumes (geocages). The focus is on the point in relation to other objects.
- *Physical functions:* Points (concerns constraints on *movement* around the point, e.g. conflict prediction and resolution), position awareness systems (limitations and capabilities for positioning). Restrictions in the system on, e.g. functionality for managing size and shape of points.
- *Objects and attributes:* Points/volumes, physical or virtual object(s). Usually, a virtual object contains the physical object(s), adding safety margins. Arbitrary 3D shape (volume), in the simplest case, a point (cylinder/sphere).

10. Workshop 3: expert design and discussion of concepts and visualisation of concepts

To arrive at UTM concepts that could be used for an actual city, a concept design and discussion workshop was conducted. We invited four air traffic controllers from the LFV (the Air Navigation Services of Sweden) to participate in the workshop. Three had valid ratings; three had expertise in safety and drone operations; and one was expert in the airspace used the workshop case. All four participants were present on the first workshop day. Three participants were present the second day.

10.1. Procedure

The workshop consisted of 5 working blocks of 45 minutes with 15-minute breaks, each focusing on the design of one concept. The first day took four hours and included an introduction to the project, and three blocks. The second day took two hours and included two blocks, and a wrap-up. Audio and video recordings were made using two cameras and external microphones. The blocks were centred around the following themes: geofencing, regular events, irregular events, planning. Each of the four thematic sections had three subsections, except for the last one about planning that had two. The geofencing thematic section had the subsections city planning, time-limited events, and drone play; the recurring events section had the subsections drone goods transports, drone taxi services, and concerned neighbours; the seldom events section contained the subsections spontaneous protests, air ambulance transport services, and severe weather; the planning section had the two subsections letter of regulation, and submission of comments on outsourcing of operations. Note that the results section is centred around concepts, not themes.

Participants alternated between discussing during sketching, and discussions around the sketches. The aim was to discuss what the UTM system would need to do, and also discuss what the human operator role could be (allocation of physical supervisory functions to human operators or other system components).

10.2. High-fidelity visualisation, context, and materials

Again, the high-fidelity visualisation of Norrköping was used (4a) for the participants to get an impression of what drone traffic in the city could look like. The further developed visualisation (compared to the version used in workshop 2) now also visualised a detect-and-avoid algorithm (and drone avoidance movements). The traffic in the visualisation showed rings around conflicting drones when drone conflict detect-and-avoid was used. This gave an impression of traffic congestion when using only one traffic layer, with lateral avoidance manoeuvres.

To the participants, we presented the same traffic scenarios as in workshop 2. We also presented the overarching goal of UTM (the functional purpose), as well as the current state (at the time) of UTM development in the US/Europe. Finally, we presented our basic UTM building blocks (Figure 3). The main work and discussions centred around the lo-fi sketching materials (Figure 7). Materials consisted of maps (three zoom levels of Norrköping), in two variants (satellite maps, or city street maps); drone markers: small and large, several colours; pens.

Various props were used during the workshop's different assignments to give them a thematic framing and focus. The city planning subsection used various maps of Norrköping. For the time limited event subsection, the air traffic controllers were given a journal with a year planner filled with important city events. The drone play subsection was in the form of an email exchange from the municipality's technical office. The drone goods transport assignment was given as a PowerPoint pitch themed as the municipality's business office. The drone taxi services were a pamphlet from the fictional company AirLyft. The concerned neighbours had a letter published in the local newspaper. The spontaneous protest, and the air ambulance transport subsections were presented as video recordings of such events. The severe weather warning was given as an update from the Swedish Meteorological and Hydrological Institute. The letter of regulation task was a hypothetical letter to the air traffic controller agency from the Government Offices of Sweden for 2018.

Scenario props were also used, such as a made-up advertising for future service providers (e.g. Airlyft, an imagined drone taxi company). The purpose of scenario props was to make the scenarios more life-like, inspiring the participants.

11. Results and visualisation alternatives

Based on the workshop, the visualisation was developed further as a more intricate design fiction. After each concept below, we present an example from the design fiction. It does not strictly follow the workshop examples but is based on further discussions in the design team. The visualisation adds the potential of back-talk from the material (the dynamic and interactive simulation and visualisation), potentially highlighting emergent issues.

We implemented the following traffic patterns:

- 'last-mile' package deliveries, by truck
- Package deliveries from a warehouse/several warehouses
- Random point-to-point traffic
- Manually added geofences
- Interaction with the airport, between drones and landing aircraft (geofence)

In the workshop we developed the following five concepts, and subsequent visualisation examples:

11.1. Concept 1: manage airspace with few drones

Using drone markers, the participants discussed capacity of manual control, using points as the main control approach. The participants thought that between 2 and 5 drones realistically could be managed by a single controller, even though they tentative placed 30 markers on the map. The participants thought that this concept could be used for places with very low traffic, with humans in the supervisory role. To go above this number, drones would need to have autonomous/automated detect-and-avoid.

Visualisation. The visualisation in this case mostly confirms what the ATCOs envisioned using lo-fi props. In Figure 4 the spheres represent drones. The low-density situation appears manageable by using the visualisation of points, and especially with the added conflict detection in Figure 4(a). The (red) squares in Figure 4 (b) are a heat map, indicating a historical build-up of conflicts, all over the map. If the task for one controller is to (manually) avoid conflicts by monitoring and giving directions to drones, then this task appears unmanageable, considering the amount of conflicts indicated by the heat map.

Concept summary:

- Situation/Framing: The exploration started from the perspective of traffic intensity. This confirms what we initially assumed, and the visualisation strengthens this, that manual monitoring based on points would not be viable for high-intensity UTM.
- Functional Purpose: Manage airspace with five (2–5) drones.
- Generalised function: Point-based supervisory control (monitoring).
- Physical function: supervisory function allocated to human operator, limited to about five drones;
- Objects: Points representing drones, as interface objects.

11.2. Concept 2: manage shared airspace with airports

This UTM concept relies on two simple building blocks: First, a 3D exclusion volume (geofence) for landing aircraft to the airport (Figure 5). Second, autonomous drone traffic (free flight) outside of the geofence (i.e. in a surrounding volume). They thought that this would be useful for ATM integration in the UTM airspace, separating drone traffic from regular air traffic when traffic to the airport was active, allowing it at other times. The air traffic controllers also suggested that drones that fly lower than the height of surrounding buildings should not be affected.

Visualisation. Figure 6 shows the concept implemented in the visualisation. The lines represent drone trajectories. It is a simplified geofence going all

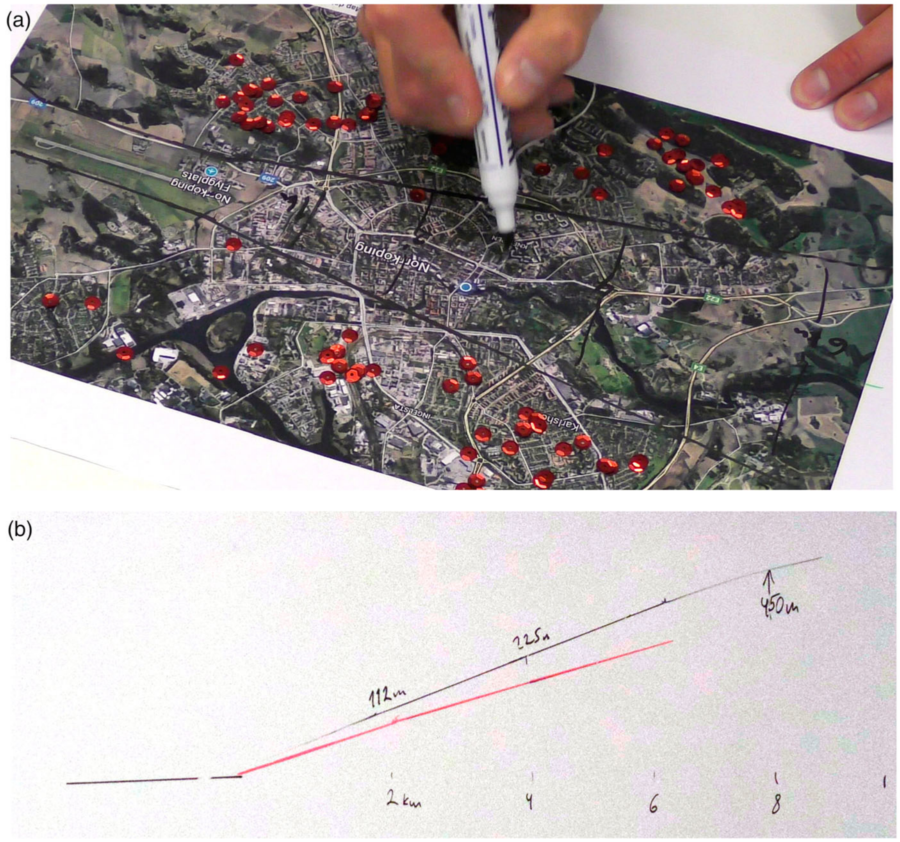

Figure 5. Concept 2, exclusion zone for ATM integration. (a) top: geofenced area, (b) bottom: depth profile.

the way down to the ground and is thus somewhat too large. It nevertheless shows a new issue, not discovered in the workshop with the usage of scenario props, but immediately evident in the visualisation: congested corners and quite long trajectory lines. The congested corners occur also with other uses of geofences and is thus an example of a recurring pattern.

Concept summary:

- Situation/Framing: The exploration started from the perspective of requiring separation between different air traffic types (drones, regular traffic). The use of the visualisation discovered a need to also manage congested corners, a particular sub-process with safety issues that may occur. It also showed an issue with airspace efficiency (long trajectory lines)
- Functional Purpose: Manage shared airspace with airports, efficiently and safely
- Generalised function: Volume-based supervisory control for area that could interfere with airport operations.
- Physical Function: The visualisation showed congested corners and long trajectory lines when using the geofence.
- Objects: Points representing drones, lines representing trajectories, 3d objects representing geofences, as interface objects

11.3. Concept 3: capacity monitoring

With concept 3, the participants returned to discussing the human role, while discussing the issue of airspace capacity. The concern was that even with autonomous detect and avoid, there could be a limit to the airspace congestion level in which self-separation would work.

The grid was a novel concept not presented to the participants during the workshop. The grid divides a plane/layer into smaller areas (squares) horizontally. The UTM principle of concept 3 is to monitor traffic versus the capacity of the grid squares (see the hand drawn division into a grid, Figure 7). Grid squares could also be used as the basis for geofencing (green square with an X, Figure 7).

Subsequent to the workshop, we have found that the use of grids has also emerged in other strands of UTM research, for instance to auction out and reserve blocks of air to airspace users. This is also similar to the 'air parcels' concept (Foina, Krainer, and Sengupta 2015) in that it frames the issue in terms of ownership of the airspace.

Figure 6. Airport geofence. Geofenced area in light transparent colour. Background generated from GSD-Ortofoto25 and GSD-Höjd-data, grid 2+ © Lantmäteriet.

Visualisation. The grid squares are visualised in Figure 4(b), as a heat map. The grid squares become visible when there is a build-up over time of conflicts between drones in the square. In this case, an animation is needed to actually see the problem with the concept. The problem is similar to the issue with concept 1. The drones move too fast, and there are too many overloaded squares, for it to be practical for one human controller to monitor each overloaded square for 'incoming drones', to avoid increased overload. Further, even the information about the overloaded squares seems hard to use. Now, if these were 'hardened' into geofences, it is easy to imagine that other squares would immediately turn red instead. This suggests that the concept might not work, at this traffic intensity, if the monitoring function is implemented as automation either. With this even distribution of flights, the visualisation indicates overload that must be managed in a more strategic fashion, by managing traffic in some other way (need for reframing of the situation). Thus, when visualising and animating the concept, it attained other qualities than when using the lo-fi props.

Concept summary:

- Situation/Framing: The exploration started from the perspective of (high) traffic intensity. The use of the visualisation indicated that with extensive overload of grid squares, the concept cannot be used on its own to manage traffic.
- Functional Purpose: Capacity monitoring, safety
- Abstract Function: Capacity estimation
- Generalised function: Grid-based supervisory control to monitor traffic versus airspace capacity
- Physical Function: The visualisation showed the (extensive) use of detect-and-avoid in the air traffic, with a too high traffic density.
- Objects: Heat map (coloured grid squares) representing traffic overload in volumes of air

11.4. Concept 4: separate of different kinds of traffic, manage congestion

This concept (Figure 7) extends concept 2, with additional UTM structures. It adds layered traffic, in five layers, each with its own grid. The air traffic controllers suggested that the UTM airspace could be fruitfully segmented into several layers depending on the technical capabilities of drones flying inside that airspace. Alternatively, it would be divided according to what kind of service that would be delivered, and what that requires.

Drone taxis (human passengers, PAV) on top was seen as the safest layer, assuming that traffic above constitute a bigger threat than traffic below (similar to Metropolis, (Sunil et al. 2015)). Lowest level for emergency response and similar community services. The participants believed that there might be a need for special permits for particularly sensitive transports, and

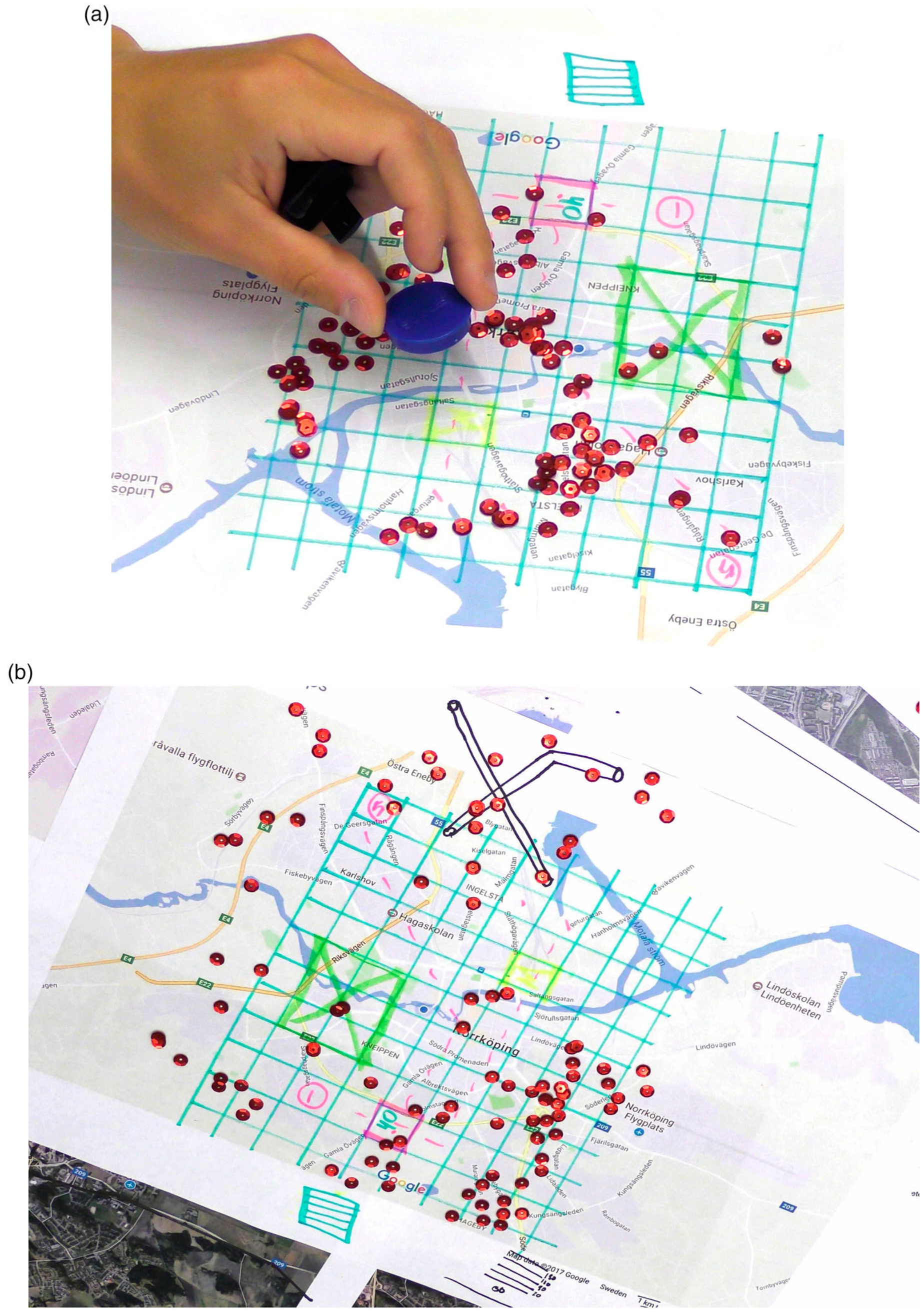

Figure 7. (a) Concept 3 and 4, (b) concept 5

they discussed whether those transports might need to be invisible for other drones. Levels in between could be used for commercial traffic. The lowest level starts at 50 m, each level is 20 m high. Exclusion volumes can be added to the grid, e.g. for contingencies or drone taxi landings (see green square in Figure 7).

Visualisation. A somewhat different concept of layers was implemented. In Figure 8, layers are firstly based on traffic type, with delivery trucks (blue pucks) and other kinds of local drone traffic on the lowest layer. Above, a main traffic layer separates traffic by direction, gradually increasing altitude with each horizontal direction degree, resulting in 360 altitude steps. Each altitude-direction pair is represented by a different hue. The hue is indicative of the current drone altitude, shown on the sphere, but also on the trajectory line. In this concept, traffic in opposing directions is always separated 50 m vertically, traffic at a 90-degree angle is separated by 25 m, regardless of direction of flight. This greatly reduces congestion*)*, in a predictable fashion, especially in situations with congested corners.

Concept summary:

- Situation/Framing: The initial frame was that different kinds of traffic should not be mixed. However, when

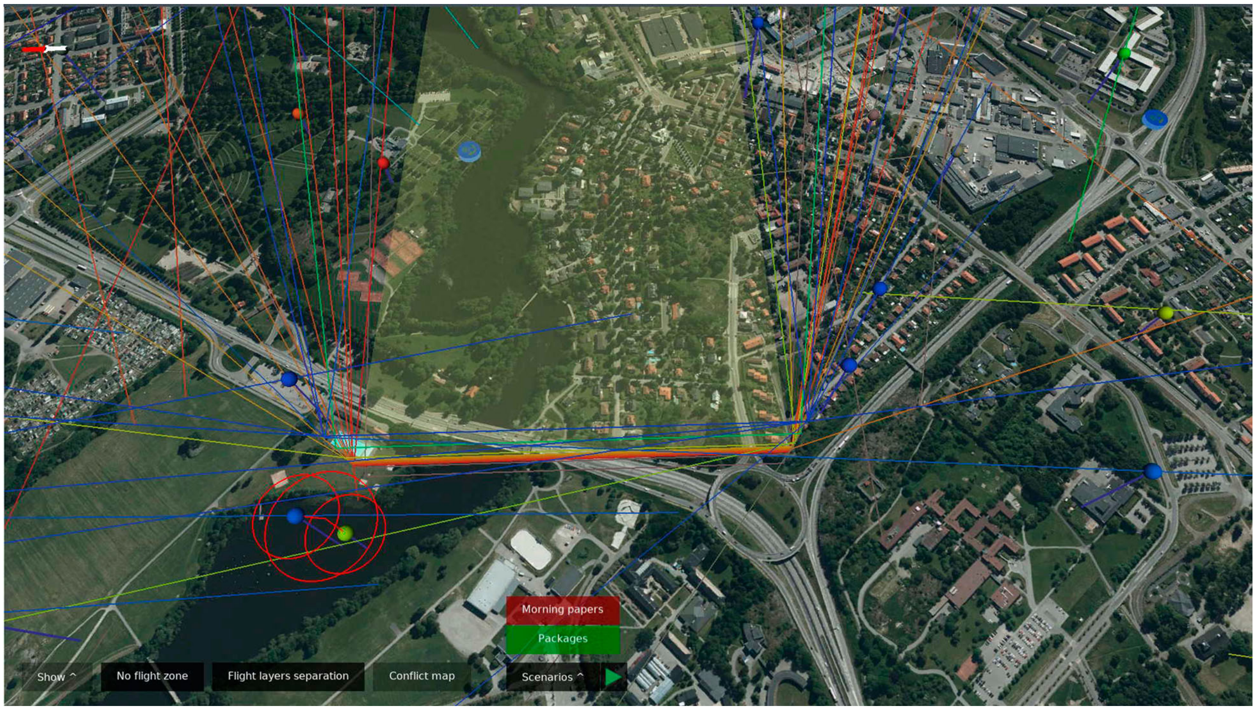

Figure 8. Layered traffic. Background generated from GSD-Ortofoto25 and GSD-Höjddata, grid 2+ © Lantmäteriet.

developing the hi-fi for C4, congestion had arisen as a core issue in the design work, e.g. C1–C3. Therefore, it was re-framed as managing traffic to reduce congestion.

- Functional Purpose: Separate of different kinds of traffic; manage congestion
- Abstract Function: Airspace efficiency estimation
- Generalised function: Layering for different kinds of traffic. Specific layer implementation (see above) for congestion management. Performance indicator for supervisory control to monitor congestion.
- Physical Function: In this case, we included a global measure (performance indicator) of the use of detect-and-avoid in the simulated traffic (a number, not shown in the figure), in addition to the heat map indicating congestion.
- Objects: Different colours, 3D as interface objects representing traffic at different altitudes

11.5. Concept 5: manage simple or noisy drones

This concept (Figure 7(b)) focused on drones with low capacity. A low-cost drone could have limited detect and avoid capacity. Therefore, traffic with those drones was enclosed in lines/tubes. Each tube uses space in one layer, crossing tubes thus uses two layers. Participants also discussed that drone noise could be hidden by flying in already noisy areas (e.g. over roads), again using a tube network. This would also include specific points for loading/unloading in the tube network. Traffic outside tubes was seen as high performance autonomous detect and avoid, as in the previous concepts. The discussion circled around the complexity that extensive tube usage would result in. They concluded that this concept of direct a-b traffic using tubes was of limited use as the main concept for traffic management but could be used for specific operations.

The air traffic controllers foresee several problematic questions and potential future conflicts regarding the balance between personal integrity and privacy on the one hand and the potential opportunities offered by drone technology on the other. Drone lanes that follow current roads might not cause perceivable noise pollutant but it's not obvious that people will accept noise pollution from drones that fly over their backyards or past their windows a few stories up in an apartment building. The air traffic controllers felt that such considerations must be resolved by politicians but also indicated that it might mean that central drop-off points for drone deliveries will be a more accepted solution in many cases rather than direct home deliveries. This gives rise to a new traffic pattern (hub-to-hub).

Visualisation. Subsequent to the workshop, we visualised drone traffic as lines (Figure 9). The (red) squares indicate hotspots, were the drones frequently fly too close to each other. Like with concept c1, what we see confirms the ATCO view from the workshop. If the trajectory lines are to be separated as tubes, this will not be

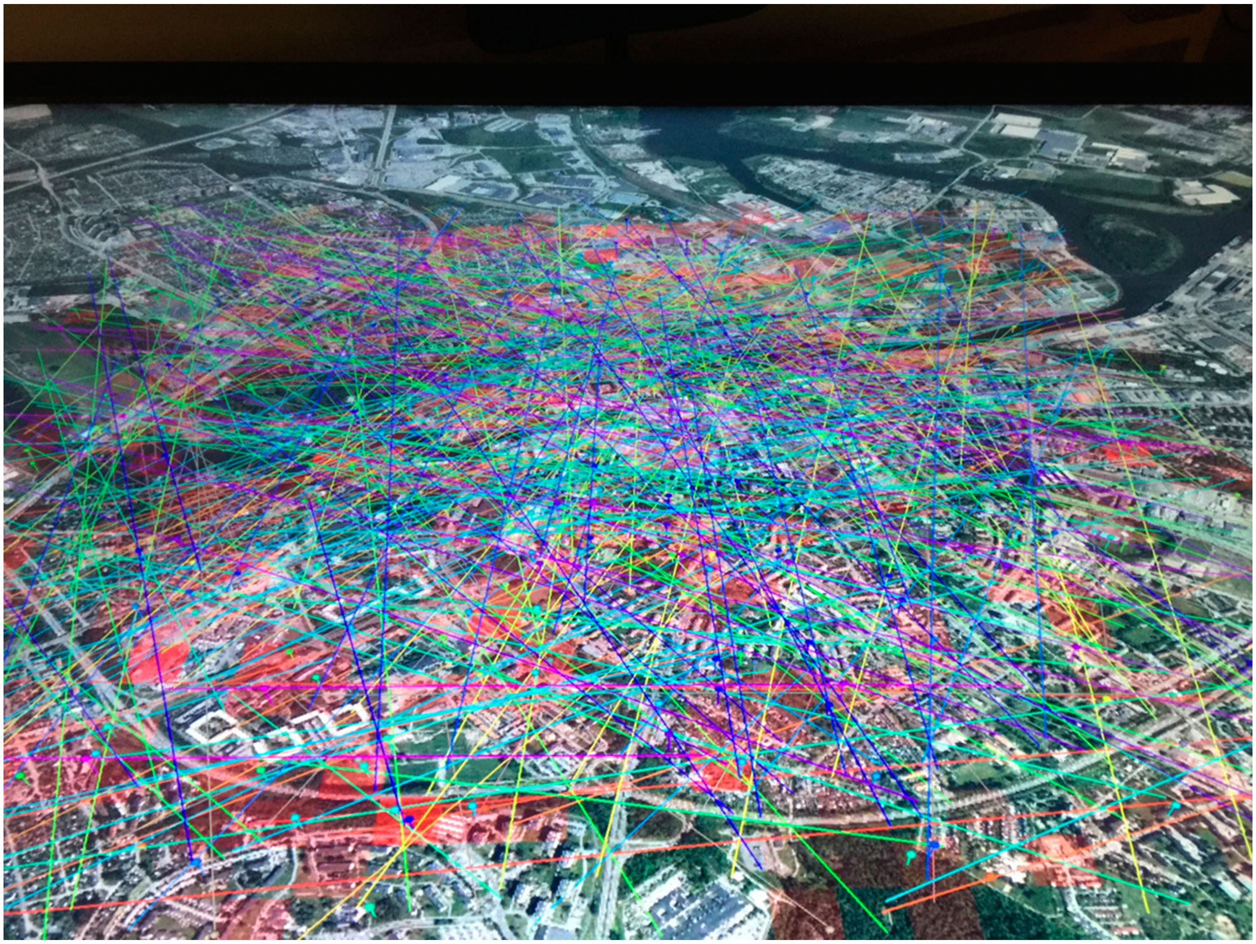

Figure 9. Random point-to-point traffic pattern. Background generated from GSD-Ortofoto25 and GSD-Höjddata, grid 2+ © Lantmäteriet.

manageable manually by one controller, in traffic examples with extreme traffic density like Figure 9.

Visualising another traffic pattern, the point-to-point delivery from a warehouse, we see a distinctive 'fan-out' of traffic (from both warehouses, Figure 10. With our layers concept, traffic going in roughly the same direction (but not being part of the 'fan' pattern) would the major interference. We see that traffic going through the layers is indeed an issue, with a steady stream of drones going up and down at the same point (over the warehouse).

Concept summary:

- Situation/Framing: Initially, the situation was framed in terms of drones with poor detect-and-avoid capacity. The use of the lo-fi materials and discussions led to a re-framing of the problem, in terms of privacy and noise. They were also doubtful about the value of the concept with extensive use of tubes. This issue was confirmed when viewing/interpreting trajectory lines as tubes in the visualisation of high-density traffic. In the visualisation using the fan traffic pattern (the two warehouses), the issue was different, and emerged when two fans crossed, especially over a warehouse where the vertical movements reduced the separation effect of layering.
- Functional Purpose: Privacy, noise.
- Generalised function: Hub-to-hub traffic pattern, fan traffic pattern
- Generalised function: Tube-based supervisory control, monitoring tubes to avoid tube crossings.
- Physical function: traffic interference with crossing traffic in fan-out pattern and start/landing sites.
- Objects: Lines representing tubes, as interface objects.

12. Summary

Tables 2–4 show the incremental progression and contributions from the different design activities to the WDA. Initial design work (workshop one) resulted in a tentative initial frame, of traffic patterns, and of the need to be able to adjust for them dynamically (addressed in concept C4). Also, some abstract functions, such as service-

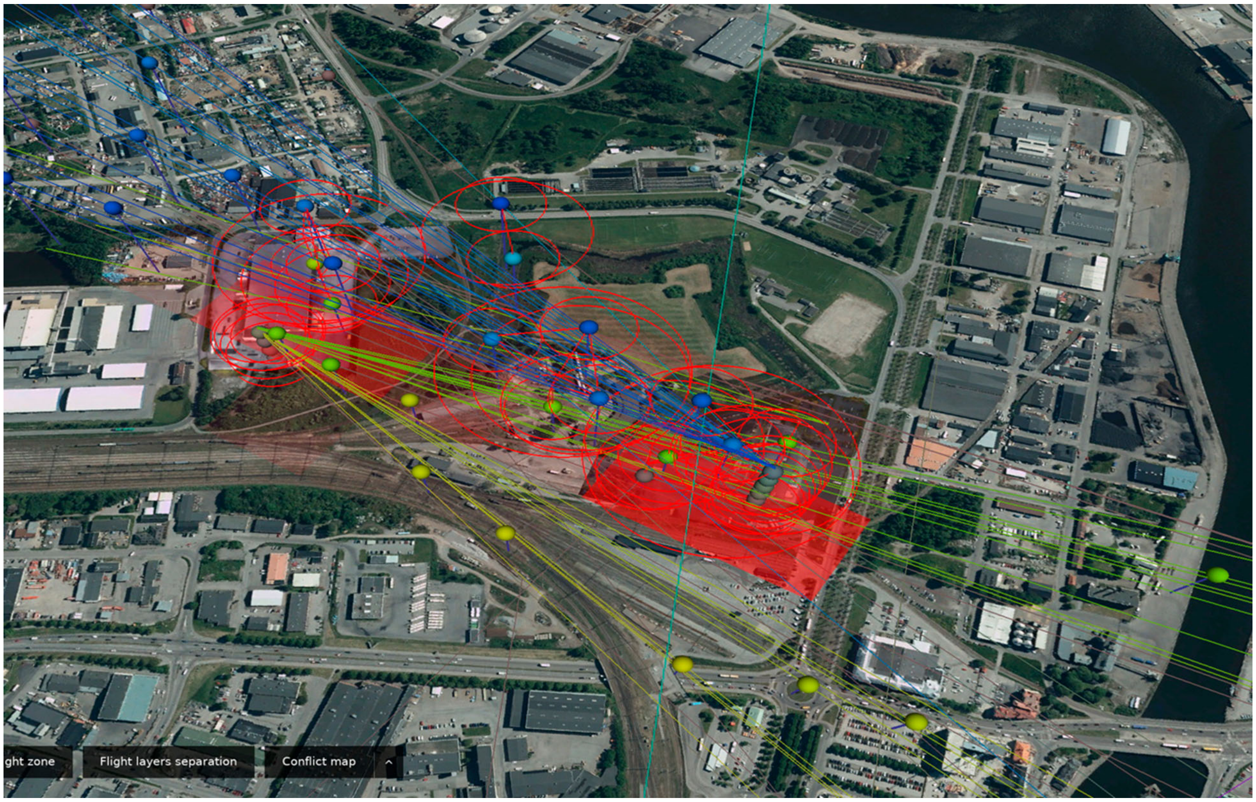

Figure 10. Fan-out (delivery from warehouse) traffic pattern (two warehouses). Background generated from GSD-Ortofoto25 and GSD-Höjddata, grid 2+ © Lantmäteriet.

dependent values and constraints were identified, and detailed service concepts, that have not yet been explored extensively in further design work. Workshop two centred around the ability to manage conditions for safe traffic. Further design explorations focussed extensively on this issue, although they did not go in the direction suggested in the workshop – to explore traffic routing primarily over buildings and gardens (increasing the risk of crashes there), versus traffic primarily over roads.

The use of WDA in the UTM concept design phase firstly highlights the extent of each design exploration. Each exploration focuses on a system to manage that particular situation with its traffic processes. The functional purpose of concepts 1–5 indicate the limits and focus of the exploration, on what could be specific sub-functions or sub-situations in a larger UTM system. They also reflect core issues in some of the situations examined, that could become core functional purposes of UTM (C5, noise, privacy).

The airspace design objects were introduced to the workshop three participants, as a starting point for their work, and as a means of achieving divergence in concept exploration. As a material, the building

Table 2. Workshop 1–2 WDA.

Level	Traffic management
S	*WS1* Drone traffic in cities: commercial or recurring operations; peer-initiated operations; high priority irregular operations *WS2 Contingency management*
FP	*WS2 Safety*
AF	*WS1* Service-dependent priority and value measures
F	*WS1* Changing airspace design to match traffic variations; *WS2* monitor conditions versus drone performance limits;
PF	*WS1*: overarching traffic patterns (variations over the day, varying priorities, varying planning horizons) *WS2:* landing sites (houses or roads), drone reliability within performance limits, drones with various performance

Table 3. Building blocks WDA.

Level	Volumes	Layers	Line	Point
F	Encapsulate; monitor (borders and capacity)	Encapsulate; monitor (borders and capacity, vertical passages)	Encapsulate trajectory; separation of trajectories, line segments,	Encapsulate (potentially moving) points; monitoring and separating points
PF	Perimeter constraints of virtual 3D volume	Altitude constraints of virtual layer	Virtual intersections, segments	(constraints regarding) movement of points
O	3D shape, location, size	layer, stack of layers	Virtual object (line or tube), network, location, size	shape of encapsulation volume

Table 4. Concepts WDA.

Level	C1	C2	C3	C4	C5
S	Low traffic intensity	Different traffic types, congested geofence corners	High traffic intensity	Different kinds of traffic that should not be mixed; manage traffic to reduce congestion.	drones with poor detect-and-avoid capacity; need to manage privacy/noise; crossing traffic in (fan pattern)
FP	Manage airspace with five (2-5) drones	Manage shared airspace with airports, efficiently and safely	Capacity monitoring, safety	Separate of different kinds of traffic; manage congestion	Privacy, noise
AF			Capacity estimation	Airspace efficiency estimation	
F	Point-based supervisory control (monitoring)	Volume-based supervisory control	Grid-capacity-based supervisory control	supervisory control based on airspace efficiency indicator and layering	Tube separation-based supervisory control; hub-to-hub traffic pattern, fan traffic pattern;
PF	Human supervisory function, limited to about five drones	congested corners and long trajectory lines when using large geofence	(extensive) use of detect-and-avoid in the air traffic, with a too high traffic density	detect-and-avoid in the simulated traffic	traffic interference with crossing traffic in fan-out pattern and start/landing sites
O	Points representing drones, as interface objects	Points representing drones, lines representing trajectories, 3d objects representing geofences, as interface objects	Heat map as interface object	Different colours, 3D as interface objects representing traffic at different altitudes	Lines representing tubes, as interface objects

blocks both have a function, shape (Table 3, O level), and a focus of monitoring (by human or by automated functions) for supervisory control (Table 3, PF level, describing constraints). Although we did not introduce he PF level to the participants (see Figure 3 for images of how the building blocks were introduced), these properties were something they nevertheless saw through the use of the lo-fi sketching materials. It was thus a starting point to evaluate the concepts 1–5 and served as a basis for re-framing during and after the workshop (e.g. judgment of number of drones that could be managed by one traffic controller through concept 1, perceived issues with line-based control during design of concept 4).

To implement prototypes for these designs, abstract functions (algorithms) were also needed, e.g. ways to calculate the capacity of the grid squares (and perhaps also to predict it), and to calculate (simulate) actual traffic flows to discover particularly congested areas over the days (the process). We implemented a basic process simulation and visualisation, to be able to prototype concepts and analysed both the expected function and emergent issues. While prototyping, we further developed the concepts from WS3. Process instances emerged at the PF (implemented function) level, and this ‘backtalk’ from the prototype in the simulation could be structured using WDA. Putting it all together (traffic patterns, concepts) generated a richer traffic process as well as a means for analysing the concepts through the back-talk of use. Although we did not test the concepts with users, we got an impression of their viability for human operators to use in UTM, that set the stage for re-framing of some situations.

13. Discussion and conclusion

This paper addresses challenges of designing future UTM concepts by integrating WDA (Vicente 1999) with conceptual designing (Ylirisku et al. 2016). The overall purpose is to explore this combination of design methods. This work differs from previous work using CWA (e.g. Naikar et al. 2003) in that no UTM concepts for cities were available as a reference, and the process (the traffic) to manage did not exist.

The conceptual designing included envisioning the future context to understand the work domain and frame the design effort. As introduced earlier, conceptual design fosters radical innovation by focusing not only on how something should be designed, but also what that should be designed (Ylirisku et al. 2016). The framing of potential future situations makes it possible to bootstrap the design process by making strategic assumptions. The framing workshops (1–2) and initial design work in the present project served this function. Our analysis of the first two workshops identified overarching functional purposes of the UTM system that we did not know before we started (Table 2), as well as an overarching value and priority measure in WS1 (service-based qualities). Whether to address service-based qualities (and not just safety and airspace efficiency) would be an important decision for UTM providers. We thus had to discover new traffic management purposes in order to set functional purposes for the WDA. Moreover, re-framing was central both during the design explorations using lo-fi materials in workshop three, and the subsequent work with hi-fi visualisation.

The exploration of concepts in hi-fi form after workshop 3 gave opportunities for re-framing, in the form of emergent issues. For instance, new sub-processes (congested corners) that could be improved by new/other traffic management functions, or breaking-points, where the concepts would no longer work on their own or not at all (e.g. point-based control with high-density traffic). We do not view the discovery of limits as a failure of the design process, but as a natural part of conceptual design. As a case in point, in the further development of C4, congestion had arisen as a core issue in C1–C3 and also C5. Therefore, when developing C4 from lo-fi to hi-fi, the situation was reframed from separating traffic of different kinds, e.g. in terms of priority (addressing the issue from workshop 3), to separate traffic in order to reduce congestion.

We identified a set of core airspace design concept building blocks for UTM based on previous work and similar domains. Those included the shape (object level) and potential 'material' properties (focus of control, e.g. entry/exit of volumes) for traffic management. Initially, we focused on core the core functions of each basic airspace design concept, such as managing borders of volumes. The designs of workshop three focused on different aspects of control. The grid was a novel concept from WS3 and was introduced to get a better picture of, e.g. congestion by dividing the airspace into squares, rather than working with the congestion of the whole airspace. This differs from previous research (e.g. Sunil et al. 2015) that focused on capacity of airspace designs, but not controllability.

Each basic airspace design concept can also have side-effects when combined (reference anonymised for peer review), such as the need to control the vertical passage through several horizontal layers (side-effect of combination of several instances of one concept). These side-effects may constitute new (sub)processes, requiring specific functions for management, making the WDA grow, and become more complex. Crucial to discovering side-effects was the focus on situations in the city to manage, and on how to structure the traffic (airspace designs) to make the traffic manageable.

The potential to combine building blocks, and to manage side-effects of combinations presents one starting point for design explorations and for WDA – the airspace as a material. Further, they can be varied by modulating intentional constraints pertaining to the airspace structure, e.g. layers where specific altitudes are used for flights in specific directions (concept 4). Constraints can also be added, based on other parameters such as traffic type (concept 4). This results in an infinite variation of particular configurations that are possible to construct/envision.

Since the airspace design concepts structured the air traffic process, they were coupled – the process and concepts were interdependent. Although this might always be the case, by incrementally adding concepts, the importance of exploring this interdependence was evident. Congested corners of geofences is a good example of this, being an emergent process. These must in turn be managed by the UTM system and its operators. We also suggest that a notion of the completeness of the WDA, to go from exploration to implementation, might be when it reaches the criterion of supporting management of the unexpected.

Even though the main knowledge contribution is methodological, the produced design artefacts, or rather the concepts that underlie them, constitute a novel and relevant contribution to UTM design. Controlling air traffic relies on the ability to build an operational picture of the situation (see e.g. Lundberg et al. 2014; Lundberg 2015), which is the reason why we included the supervisory control system in the WDA. It turned out that in particular, the notion of supervisory information functions (at the generalised function level) was important. It also bridged the use of airspace building block as a material (by indicating the focus of supervisory control), with the visualisation. We made use of the objects level to describe aspects of the visualisation, to refer to how information could presented, if the function was to be carried out by a human operator. Going further toward implementation, other steps of CWA can be used, and other techniques may be used to address the transition from CWA to traditional engineering formats (Feigh et al. 2018).

With this, we return to the initial issue of the paper, that city drone traffic did not exist in an UTM system to analyse prior to our design work. This means that our WDA could not be based on analysis of these processes initially but had to start with envisioning them in a conceptual design process. To arrive at a more complete WDA for UTM, more work is required. However, this paper has shown that conceptual designing can be a useful way to start working with a WDA for a first-of-a-kind system.

Notes

1. Currently, the acronym is not fully established, i.e. the U can stand for Unmanned or Urban, or 'Unified'. Europe uses the term U-Space, and the acronym DTM (Drone Traffic Management) is sometimes used.
2. UTM was under rapid development during our design project, and also during the writing of this paper. Basic UTM concepts for low-intensity city drone traffic were in fact put into use while the project was on-going. High-intensity city drone traffic had not yet emerged.

Acknowledgements

This study was funded by the Swedish Transport Administration and the LFV Air Navigation Services of Sweden through the project UTM50. We wish to thank all workshop participants for their valuable input to this study.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the LFV and the Swedish Transport Administration [grant number 6192].

ORCID

Jonas Lundberg http://orcid.org/0000-0001-8862-7331

References

Battiste, Vernol, Arik-Quang V. Dao, Thomas Z. Strybel, Alexander Boudreau, and Yin Kwan Wong. 2016. "Function Allocation Strategies for the Unmanned Aircraft System Traffic Management (UTM) System, and Their Impact on Skills and Training Requirements for UTM Operators." *IFAC-PapersOnLine* 49 (19): 42–47. doi:10.1016/j.ifacol.2016.10.459.

Bulusu, Vishwanath, Valentin Polishchuk, Raja Sengupta, and Leonid Sedov. 2017. "Capacity Estimation for Low Altitude Airspace." In 17th AIAA Aviation Technology, Integration, and Operations Conference. American Institute of Aeronautics and Astronautics, Denver, Colorado, USA.

Bulusu, V., L. Sedov, and V. Polishchuk. 2017. "Noise Estimation for Future Large Scale Small UAS Operations." In *Noise Control Improving the Quality of Life NOISE-CON*, 864–871. Grand Rapids, MI: Institute of Noise Control Engineering.

Carroll, John M., and Mary Beth Rosson. 1992. "Getting Around the Task-artifact Cycle: How to Make Claims and Design by Scenario." *ACM Transactions on Information Systems* 10 (2): 181–212. doi:10.1145/146802.146834.

Creswell, J. W. 2013. *Qualitative Inquiry and Research Design: Choosing among Five Approaches*. 3rd ed. Thousand Oaks, CA: Sage.

Dao, Arik-Quang V., Lynne Martin, Christoph Mohlenbrink, Nancy Bienert, Cynthia Wolter, Ashley Gomez, Lauren Claudatos, and Joey Mercer. 2018. "Evaluation of Early Ground Control Station Configurations for Interacting with a UAS Traffic Management (UTM) System." Paper Presented at the International Conference on Human Factors in Robots and Unmanned Systems (AHFE 2017), The Westin Bonaventure Hotel, Los Angeles, CA, July 17–21, 2017.

Dorst, K. 2015. *Frame Innovation: Create new Thinking by Design*. Cambridge: MIT Press.

Eurocontrol. 2017. *Is Air Traffic Management Fit for Drones?* Eurocontrol. Accessed September 18. https://www.eurocontrol.int/news/air-traffic-management-fit-drones.

Feigh, Karen M., Matthew J. Miller, Raunak P. Bhattacharyya, Minyue Ma, Samantha Krening, and Yosef Razin. 2018. "Shifting Role for Human Factors in an 'Unmanned' Era." *Theoretical Issues in Ergonomics Science* 19 (4): 389–405. doi:10.1080/1463922X.2017.1328713.

Foina, A. G., C. Krainer, and R. Sengupta. 2015. "An Unmanned Aerial Traffic Management Solution for Cities Using an Air Parcel Model." Paper Presented at the 2015 International Conference on Unmanned Aircraft Systems (ICUAS), Denver Marriott Tech Center, Denver, Colorado, June 9–12.

Holmlid, S., and J. Blomkvist. 2014. "Service Archetypes; a Methodological Consideration." Paper Presented at the ServDes. 2014 Service Future, Lancaster University, UK.

Jiancaro, Tizneem, Greg A. Jamieson, and Alex Mihailidis. 2014. "Twenty Years of Cognitive Work Analysis in Health Care." *Journal of Cognitive Engineering and Decision Making* 8 (1): 3–22. doi:10.1177/1555343413488391.

Johnson, Marcus, Jaewoo Jung, Joseph Rios, Joey Mercer, Thomas Prevot, Daniel Mulfinger, and Parimal Kopardekar. 2017. "Flight Test Evaluation of an Unmanned Aircraft System Traffic Management (UTM) Concept for Multiple Beyond-visual-line-of-sight Operations." In 2017 ATM R&D Seminar, Seattle, WA, ATM Seminar.

Lundberg, Jonas. 2015. "Situation Awareness Systems, States and Processes: A Holistic Framework." *Theoretical Issues in Ergonomics Science* 16 (5): 447–473. doi:10.1080/1463922X.2015.1008601.

Lundberg, Jonas, Jimmy Johansson, Camilla Forsell, and Billy Josefsson. 2014. "The Use of Conflict Detection Tools in Air Traffic Management – an Unobtrusive Eye Tracking Field Experiment During Controller Competence Assurance." In HCI-aero 2014 – International Conference on Human-computer Interaction in Aerospace, Mountain View, CA.

Naikar, Neelam. 2009. "Beyond the Design of Ecological Interfaces: Applications of Work Domain Analysis and Control Task Analysis to the Evaluation of Design Proposals, Team Design, and Training." In *Applications of Cognitive Work Analysis*, edited by Ann M. Bisantz and Catherine M. Burns, 69–94. Boca Raton, FL: CRC Press.

Naikar, Neelam. 2017. "Cognitive Work Analysis: An Influential Legacy Extending Beyond Human Factors and Engineering." *Applied Ergonomics* 59: 528–540. doi:10.1016/j.apergo.2016.06.001.

Naikar, Neelam, Brett Pearce, Dominic Drumm, and Penelope M. Sanderson. 2003. "Designing Teams for First-of-a-kind, Complex Systems Using the Initial Phases of Cognitive Work Analysis: Case Study." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 45 (2): 202–217. doi:10.1518/hfes.45.2.202.27236.

Norman, Donald A., and Roberto Verganti. 2014. "Incremental and Radical Innovation: Design Research vs. Technology and Meaning Change." *Design Issues* 30 (1): 78–96. doi:10.1162/DESI_a_00250.

Pejtersen, A. M., and S. Rasmussen. 2004. "Cognitive Work Analysis of New Collaborative Work." Paper Presented at the 2004 IEEE International Conference on Systems, Man and Cybernetics (IEEE Cat. No.04CH37583), The Hague, Netherlands.

Prevot, Thomas, Jeffrey Homola, and Joey Mercer. 2016. "From Rural to Urban Environments: Human/Systems Simulation Research for Low Altitude UAS Traffic Management (UTM)." In 16th AIAA Aviation

Technology, Integration, and Operations Conference. American Institute of Aeronautics and Astronautics, Washington, DC.

Prevot, T., J. Mercer, L. Martin, J. Homola, C. D. Cabrall, and C. L. Brasil. 2011. "Evaluation of High Density Air Traffic Operations with Automation for Separation Assurance, Weather Avoidance and Schedule Conformance." Paper Presented at the 11th AIAA Aviation Technology, Integration, and Operation (ATIO) Including AIA, Virginia Beach, VA, September 20–22.

Prevot, Thomas, Joseph Rios, Parimal Kopardekar, John E. Robinson Iii, Marcus Johnson, and Jaewoo Jung. 2016. "UAS Traffic Management (UTM) Concept of Operations to Safely Enable Low Altitude Flight Operations." In 16th AIAA Aviation Technology, Integration, and Operations Conference. American Institute of Aeronautics and Astronautics, Washington, DC.

Rasmussen, J. 1986. *Information Processing and Human-machine Interaction – An Approach to Cognitive Engineering*. Edited by Andrew P. Sage, North-Holland Series in System Science and Engineering. Amsterdam: Elsevier.

SESAR Joint Undertaking. 2015. "European ATM Master Plan: Executive View." Luxembourg.

SESAR Joint Undertaking. 2017. "U-space Blueprint." SESAR Joint Undertaking. Accessed September 18. https://www.sesarju.eu/sites/default/files/documents/reports/U-space%20Blueprint.pdf.

SESAR Joint Undertaking. 2018. "European Drones Outlook Study. Unlocking the Value for Europe." Accessed February 13. http://www.sesarju.eu/sites/default/files/documents/reports/European_Drones_Outlook_Study_2016.pdf.

Stappers, P., and E. Giaccardi. n.d. "Research Through Design." In *The Encyclopedia of Human-computer Interaction*, 2nd ed. The Interaction Design Foundation. Accessed June 5, 2018. https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/research-through-design.

Sunil, E., J. Hoekstra, J. Ellerbroek, F. Bussink, D. Nieuwenhuisen, A. Vidosavljevic, and S. Kern. 2015. "Metropolis: Relating Airspace Structure and Capacity for Extreme Traffic Densities." In 11th USA/EUROPE Air Traffic Management R&D Seminar, Lisboa.

Vicente, K. 1999. *Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer-based Work*. Mahwah, NJ: Erlbaum.

Xiao, T., P. M. Sanderson, M. Mooij, and S. Fothergill. 2008. "Work Domain Analysis for Assessing Simulated Worlds for ATC Studies." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 52 (4): 277–281. doi:10.1177/154193120805200417.

Ylirisku, Salu, Giulio Jacucci, Abigail Sellen, and Richard Harper. 2016. "Design Research as Conceptual Designing: The Manhattan Design Concept." *Interacting with Computers* 28 (5): 648–663. doi:10.1093/iwc/iwv040.