Runtime Norms Regulation Framework for Drones' Smart Cities Applications

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Abstract. Norms establish safety standards and operational guidelines that ensure drones operate in a manner that minimizes risks to people and properties and with respect of privacy protection guidelines based on defined legislation. Today, the widespread use of drones in smart cities applications and in the urban environment requires the establishment of adaptive norms to address various operational, safety, and regulatory challenges. In this paper we suggest a runtime norms regulation framework for drones. The objective of this framework is (i) To design a system where different organizations have different access norms using a cloud of norms. (ii) To keep drones informed about the state of the norms they are interested in during their mission (iii) To allow the update of norms tolerance based on emergency situations.

Keywords: Norms · Smart Cities · Drones

1 Introduction

Drones play an important role in smart cities [1]. Many governments are already introducing drones in multiple functions like city monitoring, transportation and infrastructure protection [2]. However, the fixed nature of access regulations for different areas and regions restricts the wide deployment of drones, thereby limiting their utilization in areas where they might be required. Recently, there has been growing research advocating dynamic access control mechanisms, particularly in scenarios that require flexibility in response to real-time events such as emergencies and weather changes [3, 4]. Norms refer to the behavioral guidelines promoted by a social group or the majority of individuals within an ecosystem. The management of these norms facilitates the autonomous coordination among individuals or agents with homogeneous/heterogeneous objectives. This is particularly important in the evolving field of unmanned air vehicles, where regulatory frameworks are playing a crucial role in ensuring the real-time adaptability of drones to the changing environments, procedures, and situational requirements

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related to their operations. In smart cities, regulatory norms can change based on factors such as traffic conditions, weather, or emergency situations. Because of their dynamism, autonomy and flexibility of agent modeling, Multi Agent Systems (MAS) can be considered as one of the most promising approaches to model autonomous, decentralized, and adaptive operations. MAS enables drones to quickly adapt to these changes through real-time communication and negotiation among agents, ensuring compliance with current norms while maintaining operational efficiency. Within this context, in this paper we suggest a runtime norm regulation framework using MAS. Unlike pre-defined or static norms, this framework allows drones to autonomously adjust their behavior based on current conditions, which is crucial for the complex, unpredictable nature of smart cities. Access norms or access rules specify what geographical areas (spatial boundaries) agents are allowed or restricted to access based on pre-established geographical zones (attributes) or based on other additional criteria such as the dynamic factors like time, weather conditions, or special events. Also, it allows the regulation of access norms of regions based on emergency situations. In the first section we address the existing related work focusing on norm management and regulation. In the second section we present the proposed runtime norm regulation framework using a scenario as a prototype. In the third section we discuss the advantages and limitations and possible improvement of the current version of the suggested framework. Finally, a brief conclusion is presented in the last section.

2 Related Work

Norms are generally conceived as standards to specify good behaviours and guide individuals' activities [1]. They define the rights and duties of the members of a given society in terms of permissions, prohibitions, and obligations. Norms can be regarded as rules in the sense that each norm contains both a premise and a consequence. They can be interpreted as a special kind of soft constraints that a system can use to sanction the violations and reward the good behaviours.

Norms have been widely used as an effective approach for regulating open and heterogeneous Multi-Agent Systems (MAS) [2]. We are particularly talking about normative MAS which use norms as a mechanism for persuading autonomous and heterogeneous agents to behave according to the stated social order [3]. Norms are necessary in MAS to achieve agents' coordination and regulate their behaviours [4]. Normative systems are closely related to deontic logic which is a formal study of normative reasoning and norms (later called Standard Deontic Logic (SDL)). SDL has been a useful tool in the specification and reasoning of access control policies because the SDL introduce deontic operators.

Norms can be created by a single legislator, or they can also emerge spontaneously. In agent's societies two main approaches are possible for establishing norms which are the top-down approach and the bottom-up approach. In the first approach, norms could be static or dynamic, but they should be created by a specific authorized agent which act as norm recommender. In the bottom-up approach, a new norm will be merged when a considerable portion of agents follow it. Based on their observations, these agents should have the ability to choose to merge a new norm autonomously using their cognitive aspect. The second approach is suitable for systems with human-agent interactions whereas the first approach is suitable for regulating organizations in dynamic environment [3]. Time, place, context and risks are ones of the possible factors that could be taken in consideration in the norm emergence. The behaviour of majority of the other agents could also affect the emergence and immergence of norms. Different classifications of norms have been proposed based on different aspect, like their purpose and their scope. For example, norms have been classified in two main types: Essential norms and Conventional norms. Conventional norms emerge without enforcement and are not enforced by the entity representing the institution and no sanctions or rewards are defined for agents persuading these norms (example: greeting). Each agent expects other agents to conform to conventions because they are self-enforced. Conventions solve coordination problems when there is no conflict between the individuals and the collective interests [5]. Essential norms are used to solve or ease collective action problems when there is a conflict between an individual and the collective interests [6]. Another classification [3] groups norms as Substantive Norms and Procedural Norms. Substantive Norms define organizational relationships among members and the normative system itself by defining Regulative and Constitutive Norms. Regulative norms describe different sub-levels of ideal behaviour by means of obligations, prohibitions, and permissions while Constitutive Norms provide an abstraction to define the ontology used for describing the behaviour of the system and describe the legal consequences of actions in the normative system (for example it defines what is a restricted area and define that each flight altitude that exceed 40 m on a restricted area is counted as altitude violation).

Norm Management include the norms representation, regulation, emergence and enforcement (self-enforcement or third part enforcement). Which make it a complex system. To model normative multi agent system, logic formalization and different architectures have been proposed in the literature for the agents and the normative systems. One of the first formalization of norms is the SDL which consist of a classical propositional logic with deontic operators. Preference-Based Deontic Logic (PDL) which has been proposed to solve some paradox of SDL. Dyadic Deontic Logic (DDL) where deontic operators are dyadic deontic logics that contain binary deontic operators, and which has been also proposed to overcome some of DDL paradox. Defeasible Deontic Logic combined deontic logics (SDL or DDL) with defeasible logic. Defeasible logic is different from monotonic reasoning. It allows reasoning in the face of contradictions and allows revision of the obligations (overshadowing) by violations facts or by more specific obligations. Also, Defeasible logic has been also used to add temporal considerations for the norms (Normative Temporal Logic (NTL)).

The prementioned norms specifications has been used in normative systems to guide autonomous agent to interplay between their goals and the norms that they are trying to uphold. Norms also are behavioural guidelines imposed by social group which guide agents to achieve their goals in an acceptable manner within their social groups without compromising their autonomy [7].

Several normative agent architectures have been suggested like NoA, v-BDI, N-Jason and BEN (Behavior with Emotions and Norms). In [8] the authors suggested a formalisation to allow agents to plan for multiple goals and norms based on the utility gain of goals and utility loss of norm violations. The authors used the norms specification proposed in [9], to propose a practical reasoning approach in rescue operation scenario.

Due to the dynamic nature of the environment, norms and policies are related to contextual information. Therefore, the revision of the rules in normative multi agent system has been studied in the recent research works. Norms management become more challenging with on runtime and in open multi agent systems. In [10], the authors suggest three norm revision strategies for the agent. The first strategy is Synergy-based strategies which are based on the concept of synergy between the objective of the system and the norms. The authors define this synergy to be positive when it is likely to achieve the objective of the system when the norm is obeyed or not violated and negative when it is likely to achieve the objective of the system when the norm is violated. The second strategy is the sensitivity-based strategy which uses sensitivity analysis techniques of probabilistic reasoning aiming to make the set for norms more effective to a specific context by reducing the probability of norm violation for a given context. The third category is the category-based strategy. In this strategy, the norms are grouped based on their relations with the objective of the system that are discovered during the runtime and based on the violation of the norms.

Drones have already been an important component of transportation systems. Their variety of uses and benefits encouraged policy makers to consider the integration of this technology in transportation system. A variety of frameworks like EASA (European Union Aviation Safety Agency) aims to develop proposals to regulate drone operations based on risk, impact, performance, etc. The EASA framework specifies regulations per type of operation, define technical and operational requirements (entering a prohibited zone, pilots' qualifications…) and combine drone hardware legislation and aviation legislation. Drone also become more autonomous even in collaborative and swam systems. In collaborative multi agent systems and open multi agent systems (OMAS), in addition to aviation and hardware policies, collaboration norms [11] need also to be addressed. These norms are also named as society interaction rules. In [12], two main challenges have been identified for norms specification which are the dynamic modifications of norms (which require to interrupt or restart the collaboration) and the re-use of norms in different situations. The norms system will also allow agents to understand the impact of norm violation or obeyance on their goals and decide to adopt it or violate it [7]. In Multi-agents' system the norms management, emergency and revision have been addressed from different perspective. In the following some of the related research works will be addressed. To improve collaboration robustness between autonomous agent coalitions, the authors in [12] suggested to include normative control which specify permitted, prohibited, and obligatory actions as the relations between the agents in the same coalitions. Six subthemes have been addressed to manage norms in cooperative agents' group, which are the specification and the modification of the norms, the norms adoption, the conflict resolution, norms monitoring, norms enforcement and norms removal. The norms specification defines permitted, obligatory and prohibited actions. Norms adoptions aim to diffuse the norms in a distributed manner so that each agent will have local norms set. The monitoring aims to identify the agents that violate the active rules and identify the responsible agent and also evaluate the cost of the monitoring. In [7], the authors proposed a Utility-based Norm Synthesis (UNS) which elicits the suitable norm on the existence of unmatchable norms. Unmatchable norms are the norms that only one of them should be applied in the current context.

In [4], the authors suggest to automatically synthesis norms in online mode by modelling a norm generalisation mechanism. The proposed model aims to detect undesirable state and synthesises norms to avoid such states in the future. Norms synthesis consist of creating a set of norms which ensure that the success of the coordination which could be designed in an offline mode (at design time) or in an online mode (at run-time). Norms synthesis require state presentation and could be designed in a centralized or distributed manner. In the contrast, in norm emergence, agent choose their own norms in a collaborative way which means each agent will have a module that allow him to synthesis the norms and actively collaborate with the others agent in the synthesizing process. However, in norms synthesis, agent could passively collaborate in the synthesizing process (norms could be synthesised by observing agents' interactions).

Existing works focusing on the Dynamic Airspace Re-configuration (DAR) of Unmanned Aerial Systems (UAS) suggested to accommodate unmanned flights by offering automated services that are developed as a human-controlled process to be executed by an air traffic controller [3] or add a dynamism only on a single drone action like landing zone [4] or focus on modelling the norms management as an offline system [8]. In this paper we suggest a sort of automated DAR process modelled as a novel runtime norms regulation framework for drones only which can be applied in variety of smart cities applications. Unlike existing works, we define norm regulation as the automated real-time modification of access permissions and restrictions. This dynamic regulation ensures that agents can operate effectively within changing environmental and contextual conditions. The goal of this framework is to allow to change the access rules of regions based on the defined mission of the drone, the nature of the organization owner of the drone and the currents state of the region (events). To give a prototype the suggested framework, we use agent modelling with lightweight, publish-subscribe mechanism and relational database.

3 Norms Management Frameworks

The cloud of norms is a dimension of a collaboration framework that we have proposed in [17] which implements a five-dimensions (Mutuality, Autonomy, Norms, Administration, Governance) social model that mimics humans' reasoning and interactions enabling the drones to switch between selfish and collaborative behaviors. The cloud of norms refers to a cloud-based infrastructure that serves as a centralized repository for regulatory norms, which can be modified or accessed on-demand. This repository stores the information related to the access norms of the regions. The repository could be solicitated or/and updated on demand. This system allows real-time updates and adjustments of norms based on changing conditions, user demands, or operational requirements.

3.1 Cloud of Norms

The main idea of the cloud of norms is to allow the access rules of each region to be relaxed or tightened dynamically based on the mission of the drone, the organization owning the drone and the situation of the environment. The rules associated with each region are saved in the cloud, creating a cloud of norms and structured in SQL. This cloud stores information related to each region, type of drone, the organization's owner and the access rules. Each region is defined by a unique name and type. Each region has a set of norms with specific tolerance levels and thresholds. The tolerance refers to the permissible degree of deviation or flexibility allowed within the norm before it is considered as violated. To determine the applicability of a norm to different types of owners (organizations owning drones), each norm has an associated owner and can be in either an "active" or "inactive" state. The state of a norm can only be managed by the agent responsible for the region to which that norm belongs (NormMaster agent). Each drone aiming to access a region must send a request to the region's agent. The NormMaster agent will first log the drone's request to maintain a history of all received requests. In this request, the drone must provide details about its characteristics and mission, such as its weight, payload, speed, altitude, flight duration, and timing. All this information is essential for the norm master agent to determine whether the drone's request should be approved or denied, based on the norm's repository. Figure 1 give a detailed view about the used relational schema.

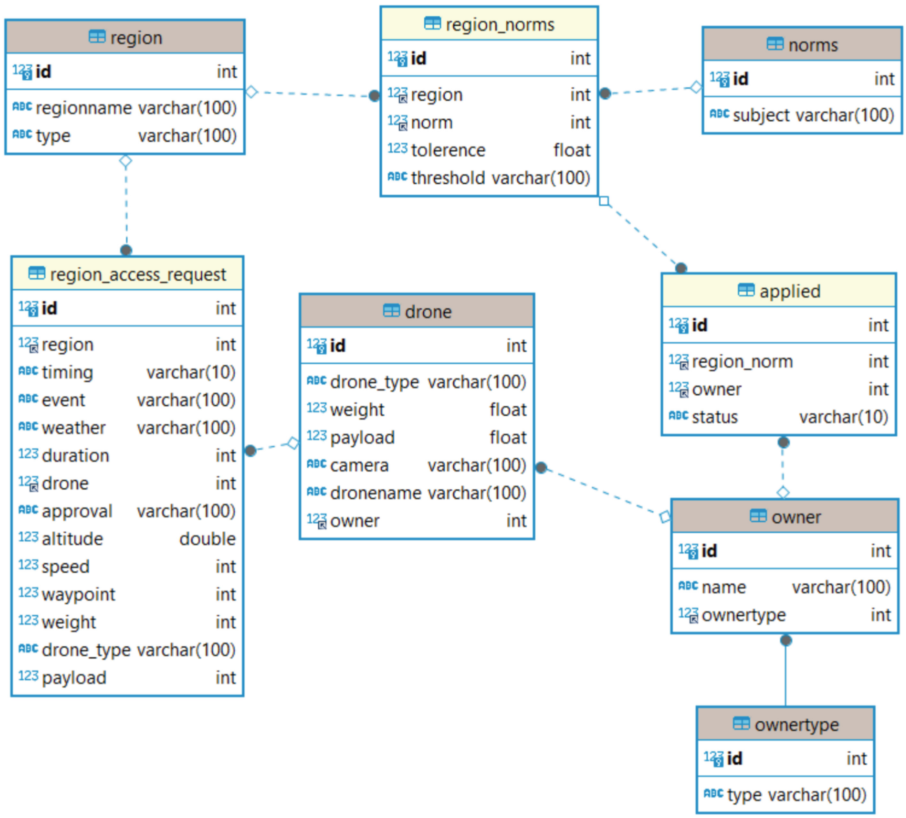

Fig. 1. Norm Master agent database schema.

3.2 Runtime Management

To simulate the concept of cloud of norms. We used Gama as agent platform. The two main type of agents are: Regions, Norms, NormsMaster and Drone. For a demonstration purpose four types of regions are defined (Farmland, Parks, Building and Residentials) where each region has a specific a set of rules that need to be applied in case of entering a region. We simulated 25 regions. Each region has a NormsMaster. The Fig. 3 shows the initial state of the simulation environment. A norm has a degree of tolerance. This degree of tolerance is defined based on the time, weather situation and context constraint as well as the type of the region, the properties of the drones and its mission. To solicit the required norms that need to be applied, the drone will send a norms specification request to the regions overlapping with his waypoint missions. In the realized simulation, the drones' behavioural norms were not modelled since the focus of the paper is not on the norm's synthesis but on norm regulation. The request includes the information about the properties of the drone (type, owner_type, battery level, camera…) and his waypoints mission overlapping with the region. The norm master agent (Region Agents) associated with the requested region will reply with a set of norms and their level of compliance which the drone should respect. The norm master agent identifies the level of compliance of each norm based on different dimension. Here, we consider drone properties and mission properties like time, space, weather, and context. This agent is also responsible for publishing the norms associated to the regions and identify its applicability to different type of owners. By requesting the norms, the drone agent subscribe to the norms of interest based on his mission. As a result, along his mission the drone agent will get notified in case of the change of the norm compliance levels. The tolerance level could be changed based on the request update trigged by the norm agent. This agent (NormAgent) fellow the state of the environment, in case of a critical event that require a relax or impose stricter access rules, this agent will send a request to the norm master to update the norm accordingly. The update concerns the change of the tolerance level which will be increased in case the rules need to be relaxed and will be decreased in case the rules need to be more tightened. For example, during emergency events the degree of tolerance of the access of the region where the event occurs will increase for emergency services allowing a flexible legal access only to dedicated drones. While during other events (like event where a crowd of people are expected: sport events) this tolerance may be reduced to increase safety. As the drone receive the sets of norms associated to the region to access and to his information, it can evaluate if his mission complies with the norms based on the norm threshold and tolerance. A drone will be able to start his mission only if it complies with all the norms requirements in all the waypoints of his mission. The Fig. 2 shows a detailed view of the communication between the agents.

This approach aims to add additional flexibility, when needed, to the mission of the drone based on their characteristics, their original organization, the nature of its mission and the current state of the environment. While it imposes more strict norms when more safety level is required.

For traceability purpose, the drone agent records all the received requests of access for his region following the schema shown in Fig. 1. After crossing the required region, the drone agent must send a mission report to the norm master agent. This report defines

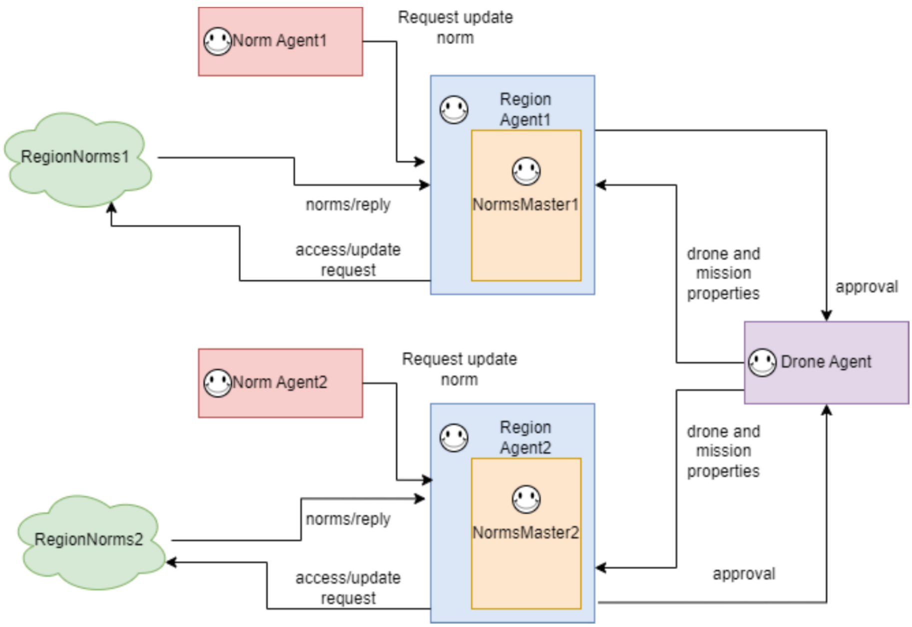

Fig. 2. Communication between agents.

to which level the drone complied with the specified norms of the region it gains access to. The mission report can contribute to identifying the reputation of the drone for future requests.

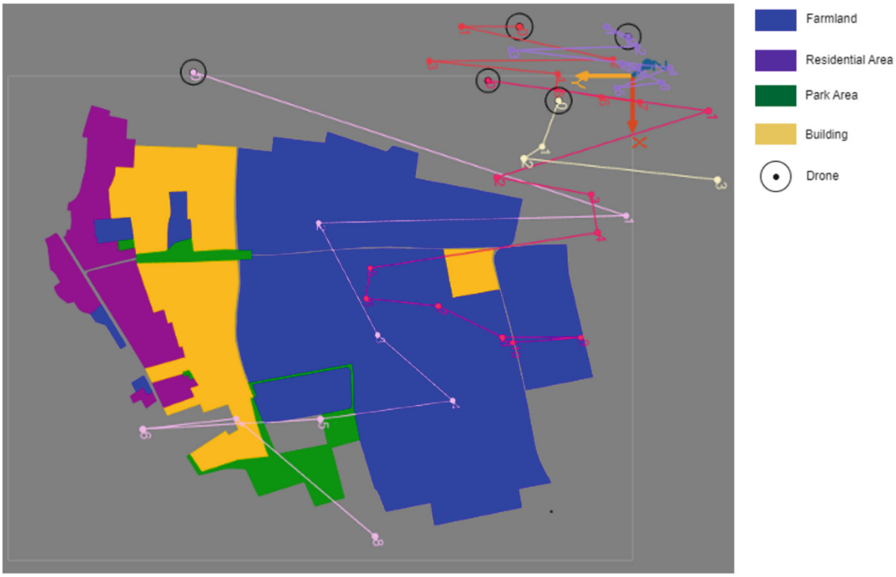

Fig. 3. Simulation Environment

3.3 Simulations Results

To evaluate the performance of the suggested norm regulation framework, 30 simulations were executed. Five drones and 25 regions were used in these simulations. Four regions of type "building", Five of type "park", 11 of type "farmland" and five of type "residence". The properties and the type of drones are detailed in the table below:

Table 1. Table of simulated drones

Drone	Organization	Type	Payload	Weight	Camera
Drone1	Police	Quadcopter	2.7 kg	6 kg	FPV (First-person view)
Drone2	Commercial Delivery	Quadcopter	10 kg	2.5 kg	FPV
Drone3	Traffic center	Quadcopter	0.8 kg	1.5 kg	PTZ(Pan-Tilt-Zoom)
Drone4	Commercial Delivery	Fixed Wing	4 kg	2 kg	NC
Drone5	Firefighter	Quadcopter	3 kg	2 kg	Thermal

For the evaluation, we will focus on two type of regions which are "Residence" and "Park". To demonstrate that our method provides a better balance granting and restricting access in response to different scenarios, we report the rigidity and flexibility ratio.

The flexibility is represented by the ability to adapt access as needed based on the change. The flexibility ratio is calculated using the Eq. (1) using the number of accesses granted (access granted to the request of the drone before starting the mission), the number of restored access events (number of accesses first non-granted but granted after events) and the number of totals of access events (Eq. (2)). More restored access indicates that the system can accommodate changes, allowing access when norms are more relaxed open an event.

The rigidity is represented by the ability to enforce restrictions. The rigidity ratio is calculated using the Eq. (3) using the number of accesses denied (access denied open the request of the drone before starting the mission), the number of access revocations (number of accesses first granted but revoked after events). A high number of revocations demonstrate that the system effectively enforces more restrictions open an event.

$$Flexibility\ Ratio = \frac{Number\ of\ \ Restored\ Access + Number\ of\ \ Granted\ Access}{Total\ Access\ Events} \tag{1}$$

$$\begin{aligned} Total\ Access\ Events = Access\ Granted + Access\ Denied + Restored\ Access \\ + Access\ Revocation \end{aligned} \tag{2}$$

$$Rigidity\ Ratio = \frac{Number\ of\ \ Access\ Denied + Access\ Revocation}{Total\ Access\ Events} \tag{3}$$

As shown in Fig. 4, which summarizes the flexibility and rigidity ratio by organization, drones from emergency-related organizations (Police, Traffic, and Firefighter) experience lower rigidity and higher flexibility ratios, allowing them more adaptable access in restricted areas. In contrast, Commercial Delivery drones face higher rigidity and lower flexibility, reflecting stricter, less adaptable regulations in sensitive regions.

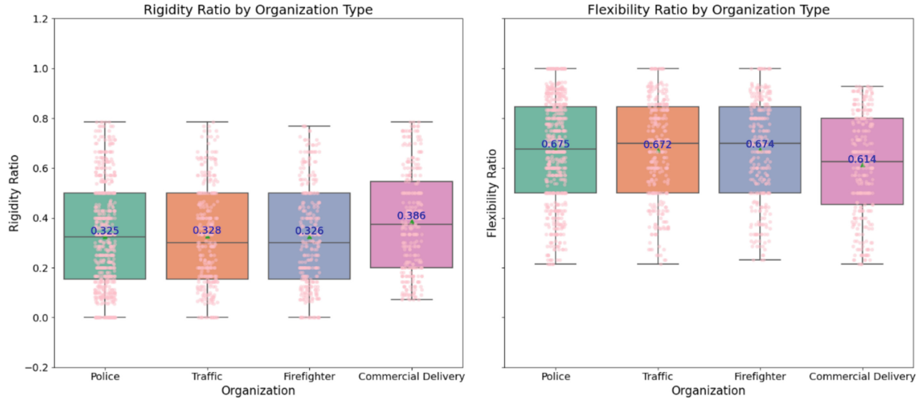

Fig. 4. Simulation results: (left: Rigidity Ratio by Organization type, right: Flexibility Ratio by Organization type)

4 Discussion

The suggest runtime norms regulation frameworks make the regulation of the norms or access rules to be managed dynamically which can unlock additional opportunities for drone application in smart cities and add more flexibility to legislation rules. One of the limitations of the proposed framework is that the drone will completely cancel its mission if one of the requested waypoints overlaps with a region which the drone does not comply with its norms. To solve this issue a possible option will be to revise the waypoint mission, like for example reducing the speed or changing the routing of the mission following the regions with more relaxed norms. This is applicable to some application contexts like for example delivery, while it is not applicable to other applications like person/car tracking.

In real smart city applications, the norm regulation can arise many challenges since the national aviation regulations establish strict, predefined rules that dictate drone operations based on static conditions like geographical zones, airspace classifications, and pre-authorized flight plans. For any change or update of the rules, an explicit regulatory approval should be obtained in real time which is not currently supported in many regulatory frameworks. Sometime, new rules are tested in a controlled environment to help the regulators to evaluate the impact of new rules on safety, privacy, and compliance before full-scale implementation. The proposed dynamic framework will need to include automated communication with regulatory bodies and air traffic control to update access permissions based on current conditions which should define permissible dynamic adjustments for specific scenarios. Such system has additional liability challenges in case of safety issues, where liability protocols need to distribute the responsibilities between different entities (drone operators, regulatory authorities, rule management systems).Also, to solve conflicts between norms, determine priorities and evaluate the rule, a real-time evaluation of rules based on the specific context using a dynamic risk assessment (drone could dynamically assess the risk of flying in a given area using define rules) or using a data-driven decision-making will be an important module.

In addition, in the current version of the proposed framework, the threshold was defined and fixed for each norm. As further improvement, the threshold could be learned from the repeated scenarios. The norms master agent will be able to identify the best level of threshold for each norm based on the required level of safety and the risk report which helps to update the threshold level from the previous experience. A simple neural network can be used to update the best threshold based on the risk report. However, we believe this approach can create additional legislative challenges since most of the current drone's legislations have fixed thresholds.

5 Conclusion

The use of drones in smart cities' applications opens a variety of valuable opportunities. At the same time, the access rules and regulations create a challenge in dynamic and complex environments. Although the proposed framework adds challenges to legislation and regional access rules. We think that the proposed framework opens a wide interesting application of drones in smart cities. The proposed framework will be a part of multi-dimensional collaboration architecture for drone collaboration proposed in previous work.

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