Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)
Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio

doi: 10.3850/978-981-18-8071-1_P738-cd

A Digital Twin Model for Drone Based Distributed Healthcare Network

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In the recent years we noticed that a distributed healthcare network can improve the efficiency of the healthcare system significantly. Drone logistic network for delivering medical goods is one such example of distributed healthcare network. A trial of such network was performed near Rome by Leonardo and Telespazio Li et al. (2020), where the medical objects were delivered in 25 minutes by drone while the road journey along the coast took about 45-60 minutes. The effect of drone transportation on biological samples has also been analyzed by F. V. Daalen and Geerlings (2017). They investigate the benefits of a drone logistic system and it has been observed that there are no negative effects on the objects for a tournaround time of less than 4 hours. Back in 2020, Matternet (2020) announced a collaboration with lab facilities in Berlin to transport patients' samples from hospitals by drone. Matternet have also undertaken similar project in Switzerland with Swiss Post, to transport laboratory samples between two hospitals. Moreover, Amukele et al. (2016) conducted tests where microbiological specimens including blood cultures were transported by drone and compared with stationary specimens to assess whether the specimens are affected by drone transport. For the microbes used in the trial no significant impact was found on the specimens flown for 30 minutes. Flight tests for medical delivery have also been successfully conducted in Spain by Quintanilla García et al. (2021).

Moving towards this direction, the UK government is presently investing in the realization of an autonomous drone logistic network that allows the delivering of medical equipment and assistance to remote areas. The CAELUS project, financed by the UK Industrial Strategy Future Flight Challenge Fund, has the aim of exploring the usage of drone delivery systems for the dispatching of medical items. This paper presents part of the analyses done during the second phase of the project. The main objective is the realization of a digital blueprint - a combination of a digital twin models of the complex network and a set of optimization tools - of the drone logistic network with a twofold applicability.

The first application of the digital blueprint corresponds to the design process of the whole drone logistic network such to be optimal for the given key performance indicators as defined by the stakeholders. This task takes place in advance of the physical network construction and it is entirely performed in the virtual environment simulation. The design problem translates to a multi-objective generative network optimization as shown by Gao et al. (2019) where the network is iteratively defined, simulated and improved. The indicators considered in this work are: capital costs of investment and operational cost of the delivery, delivery time and resilience under internal and external unexpected events. In particular, the resilience is considered as the ability of the whole network system to absorb negative and unpredictable events and recover after the failure.

For this generative network optimization, a biologically-inspired methodology has been developed which extend the work proposed by Masi (2013). It is inspired by the behavior of the by Physarum organism and it has shown to perform well in many engineering problems including network topology (T. Nakagaki (2000)) and Steiner tree problems (Tero et al.

(2000)).

The methodology includes two integrated steps: the generation of a sub-optimal delivery network that is progressively optimized and the simulation over the generated network of the drone delivery system. The former is a network optimization problem while the latter, with the task of selecting the correct drones and finding the optimal routing and scheduling, can be classified as a vehicle routing problem.

The second tasks performed by the digital blueprint is the network operational problem: the on-line simulation of the digital twin during the actual operational life of the drone logistic network and optimization of its scheduling and planning. Once the physical network system is operative, sensor data can be collected from the physical systems and used to refine the digital twin models. The digital blueprint is used in this phase to simulate many possible scenarios affected by uncertainty in the medium-short period of time, and determine the optimal actions to take.

Keywords: Digital Twin, Drone Logistic Network, Vehicle Routing Problem, Network Optimization Problem.

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