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BLOODCHAINSIM – A SIMULATION ENVIRONMENT TO EVALUATE DIGITAL INNOVATIONS IN BLOOD SUPPLY CHAINS

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ABSTRACT

Blood Supply Chains are an essential element of healthcare systems. Crisis situations, such as droughts, epidemics and political conflicts, put an increasing innovation pressure onto blood establishments to enable a steady delivery of blood products at all times. Simulation provides the means to test out digital innovations for blood supply chains regarding their operational efficiency and the expected costs. However, past simulation tools for blood supply chains usually do not encompass all actors of the supply chain or are unable to simulate dynamic decision making. We developed a hybrid agent-based and discrete event-based simulation toolkit incorporating different optimization problems to enable such decision support and applied it on two use-cases in cooperation with South-African blood establishments.

1 INTRODUCTION

The provision of blood products in a timely and sufficient manner is the main task of blood supply chains. Therefore, blood establishments make use of tried-and-proven processes and operations, as the main tasks did not change much throughout the last decades. Nevertheless, the increasing occurrence of crisis situations, caused e.g. by climate change and political instability, puts a continuous innovation pressure onto blood establishments. This particularly holds true in countries, where the general population shows a low willingness to donate blood products, such as in many African countries.

During a crisis, the blood supply chain has to cope with possibly drastic fluctuations in the supply and demand of blood products as well as with a loss of existing supply chain structures, e.g. due to a worker shortage or damages to the infrastructure. Here, digital innovations such as the usage of drones and dynamic decision support tools can help to flexibly adapt to such challenging situations. However, blood establishments are often reluctant to test and implement such solutions, as they work with very limited budgets and try to avoid any interruptions to their daily operations due to the criticality of the handled products. Hereby, simulation provides the means to enable an evaluation of digital innovations in the blood supply chain without interrupting operations. However, past simulation approaches usually either do not encompass all actors in blood supply chains, assume that a centralized actor can control all actors of the blood supply chain, or do not consider the effects caused by the occurrence of a crisis (Osorio et al. 2015).

In the context of the research project "Blood Information System for Crisis Intervention and Management" (BISKIT) funded by the German Federal Ministry of Education and Research, we developed a simulation toolkit called "BloodChainSim" encompassing a hybrid agent-based and discrete event simulation coupled with optimization models in order to depict dynamic decision making. In cooperation with the South African Blood Establishments "Western Cape Blood Service (WCBS) and South African National Blood Service (SANBS) we applied the simulation toolkit to evaluate several scenarios, such as the dynamic allocation of mobile blood donation facilities and the usage of drones in urban areas.

2 SIMULATION METHODOLOGY & APPLICATION

The BloodChainSim Toolkit is based on the established HumLog Suite, developed by the authors (Widera, Lechtenberg et al. 2017). HumLog Suite is a hybrid agent-based and discrete event simulation toolkit based on AnyLogic, which was applied to several crisis scenarios in the past, such as floodings and evacuations of urban areas (Detzer et al. 2016). For BloodChainSim, all relevant actors of the Blood Supply Chain were modeled as separate agents capable of their own localized decision-making, separated into “push” elements originating from the blood donation centers and “pull” elements leading to the hospitals, where the blood products are transfused to patients. Furthermore, a geographical information system (GIS) was employed to properly depict locations and the real transportation infrastructure. Fluctuations in supply and demand can be modeled by using stochastic distributions. In order to portray dynamic decision making, two types of optimizations were included, following the recommendations of the German VDI Guideline 3633, page 12 (Rabe and Clausen 2015). An optimization preceding the simulation run can be used to depict strategic and tactical decisions, such as location assignments. An optimization that is executed during the simulation to determine the next simulation steps can be used to delineate operational decisions, such as a dynamic route planning of transport vehicles. Thus, the toolkit is capable of simulating the overall blood supply chain including all elements needed to evaluate the effects of introducing different digital innovations.

We applied the simulation toolkit to two use-cases in cooperation with WCBS and SANBS. In a first use case, we improved the efficiency of mobile blood donation facilities (MBDF) by the means of dynamic decision making (Horstkemper et al. 2021). WCBS operates these in a hub-and-spoke system with fixed schedules. During a crisis, staff shortages means that not all MBDFs can be operated. To select which MBDFs should be used we first apply an optimization before simulation to select the appropriate hubs and staff allocations. During the simulation, we then make use of a second optimization to dynamically choose operating locations, where the highest probability of collecting blood products currently in demand can be expected based on past donation data. The simulation shows that a substantial reduction of blood product shortages can be achieved by applying such dynamic decision making capabilities instead of relying on fixed schedules.

In a second simulation scenario we analyzed the impact of drone-based deliveries of blood products in urban areas. While drones are already in use in several African countries (including South Africa) to enable deliveries into regions where existing infrastructure makes a delivery via traditional means such as trucks impossible, it has not yet been analyzed under which conditions drones are a viable alternative in urban areas, where traffic congestions may critically delay blood product deliveries. We first select suitable locations for drone bases solving an optimization model before the simulation, to then dynamically decide during the simulation whether a truck or a drone should be employed based on traffic information from the GIS. The simulation toolkit thus can be used to evaluate the expected reduction in shortages of blood products based on the available funds for the establishment of such a drone-based infrastructure.

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