Hybrid simulation-optimization approach for planning relief-aid distribution with a real-world case study

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Abstract

Purpose – Authorities have set up numerous security checkpoints during times of armed conflict to control the flow of commercial and humanitarian trucks into and out of areas of conflict. These security checkpoints have become highly utilized because of the complex security procedures and increased truck traffic, which significantly slow the delivery of relief aid. This paper aims to improve the process at security checkpoints by redesigning the current process to reduce processing time and relieve congestion at checkpoint entrance gates.

Design/methodology/approach – A decision-support tool (clearing function distribution model [CFDM]) is used to minimize the effects of security checkpoint congestion on the entire humanitarian supply network using a hybrid simulation-optimization approach. By using a business process simulation, the current and reengineered processes are both simulated, and the simulation output was used to estimate the clearing function (capacity as a function of the workload). For both the AS-IS and TO-BE models, key performance indicators such as distribution costs, backordering and process cycle time were used to compare the results of the CFDM tool. For this, the Kerem Abu Salem security checkpoint south of Gaza was used as a case study.

Findings – The comparison results demonstrate that the CFDM tool performs better when the output of the TO-BE clearing function is used.

Originality/value – The efforts will contribute to improving the planning of any humanitarian network experiencing congestion at security checkpoints by minimizing the impact of congestion on the delivery lead time of relief aid to the final destination.

Keywords Security checkpoints, Relief-aid distribution planning, Clearing function, Congestion, Business process simulation, Business process reengineering

Paper type Research paper

1. Introduction

Effective logistics performance ensures product safety and speed of delivery while lowering costs when trading across borders, thereby benefiting countries' socioeconomic and environmental goals (Büyüközkan and Ilıcak, 2022; Ahmad *et al.*, 2022; World Bank, 2023). Logistics covers a wide range of issues, including commodity transportation and distribution, inventory management, imports and exports (Sergi *et al.*, 2021). Security checkpoints are critical for logistics performance. It is considered the only official gates through which countries can control the flow of commodities by determining the quantity and quality of these commodities, as well as their compliance with the country's security and safety standards (Pairot and Kiattisin, 2020). Security checkpoints, on the other hand, are potential sources of

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Data availability statement (DAS).

Data derived from public domain resources.

The Logistics Cluster database, available at www.logcluster.org
The Israeli Crossing Point Authority (www.mod.gov.il/)UNOCHA's database (www.ochaopt.org/data)
The COGAT official website (www.gov.il/)

The following data are publicly available to support the study's findings.

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supplier delivery disruption risk as well as a source of congestion due to tightened security-checking processes and complex control procedures, which cause delays in the transportation of goods to their final destination, impeding trade and logistics activities (Haughton and Isotupa, 2013; Ilker Topcu *et al.*, 2020). Furthermore, security checkpoint procedures have a significant impact on humanitarian logistics, as checkpoints are a major driver of relief aid access to its final destination (European Commission, 2022; Wang *et al.*, 2023). Customs controls, authorities' lack of knowledge about required products and failure to prioritize transport containing critical humanitarian aid can pose a stumbling block to relief aid delivery (WHO, 2022). Another issue is that security checkpoints are frequently closed during disasters, limiting access to affected people and adding complexity to already overburdened humanitarian logistics (Altay *et al.*, 2023). In a humanitarian context, logistics account for the majority of disaster-relief efforts. Logistics are an essential part of any disaster relief effort and are the deciding factor between successful and failed relief operations (Khan *et al.*, 2022). Thus, it has become necessary to apply novel technologies, approaches and processes to offset the detrimental effects of security checkpoints on humanitarian logistics and improve their adaptability to natural or man-made disasters (European Commission, 2022).

This was the case, for instance, in Palestine, one of the Middle Eastern countries with security checkpoints set up by Israel to control the flow of civil, commercial and relief movements into and out of Palestinian territory as a result of the ongoing armed conflict in that area (Salhieh *et al.*, 2017; OCHA, 2023a). These security checkpoints are widely regarded as the greatest impediments to logistics and transportation services in Palestine for both commercial and humanitarian reasons. It should be noted that Palestine is classified as a country that is heavily reliant on humanitarian aid to maintain its socio-economic sustainability, which is distributed on a consistent and regular basis (ACAPS, 2020). The Kerem Abu Salem (KAS) security checkpoint, later used as a case study, is regarded as one of the most important security checkpoints between Israel and Palestinian territory, serving as Gaza's primary commercial crossing and the Strip's only commercial crossing with Israel. It is a lifeline and the only entry point for humanitarian aid among Gaza's two million residents. This security checkpoint strictly adheres to security protocols that raise logistics costs and slow the delivery of goods to Gaza, impeding the work of international humanitarian organizations and private businesses (Logistics Cluster, 2014; UNCTAD, 2020; Gisha, 2020; OCHA, 2023b). This problem prompts us to pose the following research question:

RQ1. What is the security checkpoint's current performance level in times of armed conflict disaster, and is there potential for improvement? Specifically, is there an improved approach to setting up the process at the security checkpoint to reduce delivery lead-times and distribution costs throughout the entire humanitarian supply network?

Therefore, our goal is to improve the planning of relief-aid distribution by reengineering the security checkpoint process to reduce processing times for relief items, relieve congestion at checkpoint entrance gates and integrate reengineering efforts with a modified decision support tool, the clearing function distribution model (CFDM) developed by Rezeq *et al.* (2023), to optimize relief-aid distribution performance and minimize the effects of security checkpoint congestion on the entire supply network.

However, humanitarian organizations require effective tools for the process management of relief operations in the context of humanitarian logistics (Larson and Foropon, 2018) to better capture decision-making complexity in humanitarian logistics. According to Giedelmann-L *et al.* (2022), hybrid approaches that combine system dynamics and other modeling modalities are recommended. When using this combined simulation-optimization approach in humanitarian logistics research, numerical trials that are generated randomly and without field evidence are usually used (Baharmand *et al.*, 2022). Furthermore, research on humanitarian logistics is inclined to develop and combine optimization models to handle traditional humanitarian logistics challenges; however, few scholars have sought to study how models can be applied to new and freshly emerging problems (Besiou and Wassenhove, 2021). Consequently, our research attempts to fill this gap in the field of humanitarian logistics through the following contributions:

- A hybrid simulation-optimization approach was employed to enhance the quality of the proposed decision-support tool for the distribution of relief aids. This tool uses a simulation of the business process to mitigate the negative effects of congestion on relief aid distribution performance. The output of the simulation is then used as input data to estimate the clearing function, which is subsequently incorporated into the decision support tool to address congestion in the supply network. To the best of our knowledge, no previous research has combined relief aid distribution planning, specifically in relation to congestion at security checkpoints, with business process modeling. In addition, the utilization of business process simulation (BPS) results as input parameters to estimate the clearing function is a unique aspect of the existing literature on clearing functions.
- A business process reengineering (BPR) methodology was employed in this study to redesign the process at the security checkpoint and evaluate the scenarios made during the redesign process across the entire supply network.
- To provide more realistic and appropriate scenarios, the scenarios for the re-engineering method were developed in partnership with humanitarian groups that provide relief aid and deal with the process at security checkpoints, particularly in developing countries. In addition, the authorities who oversee security checkpoints and logistics service providers are involved in the development of these scenarios.
- This study is based on actual data from an unstudied real-world case: the process at Israeli–Palestine border security checkpoints. This process involves intricate procedures and strict security measures for the movement of goods, both humanitarian and commercial, from these checkpoints to areas that are unstable because of ongoing armed conflicts.

The remainder of this paper is organized as follows: Section 2 provides a brief review of related literature. Section 3 describes the research methodology. Section 4 describes the methodology, using a case study. Finally, Section 5 concludes the study.

2. Literature review

2.1 The combination of BPS and supply chain planning

Supply chain planning (SCP) is a complex business process. It deals with the coordination and integration of a company's key business activities, from raw material procurement to final product delivery to consumers (Santa-Eulalia *et al.*, 2012). In SCP, quantitative approaches such as simulation and optimization are used to improve supply chain performance and deliver the right amount of goods to the right place at the right time at the lowest possible cost (Kumar *et al.*, 2020). This section focuses on the literature that combines BPSs and SCP. BPS is a business process management (BPM) technique for quantitative business process analysis that captures resource constraints, decision criteria and random behavior in the real world (Dumas *et al.*, 2018; Rosenthal *et al.*, 2021). Starting from the study of Jain and Ervin (2005) who used modeling and simulation to evaluate improvements in business processes to evaluate the transition of a logistics and distribution supply chain to e-business, An and Jeng (2005) created a BPS model by capturing activities and related data in a supply chain scenario. This model was developed as a system dynamics model, and simulation results based on the system dynamics model were used to improve the original BPS model. A BPS approach was proposed to support the redesign of logistics, sustainability and food quality analyses in the food supply chain (Van Der Vorst *et al.*, 2009).

A combination of SCP and BPS was used by Zhang *et al.* (2010) to provide a mathematically sound foundation for the reengineering of an order fulfillment process in the supply chain. Wu *et al.* (2011) developed a supply chain business process model using Petri net tools, analyzed the enterprise distribution business process and proposed a process improvement optimization model based on simulation data. Wang *et al.* (2011) used a BPS to assess the value of collaboration in a supply chain. Windisch *et al.* (2013) examined forest biomass supply chains in various operational settings to identify the business processes and stakeholders involved. BPS was used to estimate the work time spent on organizational and managerial tasks in the supply chains. Mousavi *et al.* (2019) used model-based system engineering to create conceptual models for order management process simulations within complex semiconductor manufacturing SCP systems. Finally, Schätter and Morelli (2021) presented a method for combining BPS and supply chain risk management to develop a resilient supply chain.

2.2 Hybrid simulation-optimization approach for humanitarian logistics

Many studies have used a hybrid simulation-optimization approach to optimize supply chain performance by solving a variety of problems in production, storage and distribution, transportation, logistics and finance (Yoo *et al.*, 2010; Figueira and Almada-Lobo, 2014; Saif and Elhedhli, 2016; Ivanov *et al.*, 2022). These methods combine simulation and optimization to find optimal solutions to complex optimization problems (Tordecilla *et al.*, 2021), for instance, in queuing systems, simulation can be used to compute parameters, which can then be incorporated into mathematical programming models (Figueira and Almada-Lobo, 2014). The first simulation-optimization package was released in 1994. Since then, most simulation system developers have incorporated some form of model optimization or improved output analysis into their decision support tools (Donald, 1999).

In the context of humanitarian logistics, few studies have used the hybrid simulation-optimization approach. Sahebjamnia *et al.* (2017) proposed a hybrid simulation-optimization method for developing a discrete-event simulation-based decision support system to determine the best facility location and relief item distribution plan based on coverage, total cost and response time. Using a rule-based mechanism and simulating post-disaster conditions in the pre-disaster phase for each set of possible scenarios and decision variables, a simulation was conducted to investigate the set of good decisions. Alizadeh *et al.* (2019) developed a two-stage stochastic programming model for a casualty collection point network design problem. The simulation model was used to generate the number of causalities and the available transportation capacity. Karatas and Yakıcı (2019) used a hybrid simulation-optimization approach to modify the classic *p*-median problem location model to account for distances to backup services, and discrete event simulation was used to evaluate the performance of location schemes obtained from the deterministic mathematical model. Salehi *et al.* (2019) created a simulation-optimization model for designing a blood supply chain network in the event of a potential earthquake in Tehran. A Monte Carlo simulation method was used to implement and evaluate the mathematical models. Ghasemi and Khalili-Damghani (2021) presented a robust simulation-optimization approach for preparedness planning. Numerous earthquakes have been designed and tested using a simulation approach to estimate the mean and variance of demand for relief commodities. The output of the simulation was used as the input for the stochastic demand behavior parameter of a mathematical model for a multiperiod location-allocation-Inventory problem.

Some studies have proposed a hybrid simulation-optimization approach to measure healthcare responsiveness during a crisis, with a focus on the problem of congestion and improper workload distribution. For example, Farahi and Salimifard (2021) proposed a hybrid simulation-optimization approach to measure healthcare responsiveness during a crisis. Various crisis scenarios and emergency department systems have been designed and modeled using discrete-event simulations. On regular and emergency bases, a simulation technique was used to assess the workload. Hatami-Marbini *et al.* (2022) proposed a simulation-based optimization approach for determining the best location of emergency medical centers and assigning ambulances to the selected centers to maximize the survival rate while minimizing the total emergency medical service system costs. The optimization model results were used as the primary scenario to create the simulation model. Finally, the study of Mousavi *et al.* (2022) proposed a hybrid simulation-optimization approach for disaster management with maximum coverage in the immediate aftermath of an earthquake. A simulation was used to determine the optimal capacity of the medical centers and simulate the behavior of casualties at the start of the disaster.

The relevant literature was categorized into two groups, as Table 1 shows. The first group illustrated how SCP and BPS were combined. This review found that the combination of BPS and

Table 1 A Summary of the related literature

Author	*Combine BPS and SCP*	*Commercial supply chain planning*	*Humanitarian supply chain planning*	*The purpose for using the combination of SCP and BPS*
The combination of business process simulation (BPS) and supply chain planning (SCP)				
Jain and Ervin (2005)	✓	✓		To assess how well systems and business processes have been improved in a supply chain for distribution and logistics
An and Jeng (2005)	✓	✓		To present ideas and heuristics to generate supply chain system dynamics models
Van Der Vorst *et al.* (2009)	✓	✓		To analyze the impact of food quality change and environmental load in redesigning food supply chains
Zhang *et al.* (2010)	✓	✓		To provide a way for employing integration and coordination across the entire supply chain to reengineer the order fulfillment process (OFP) and sustain supply chain management
Wu *et al.* (2011)	✓	✓		To analyze the enterprise distribution business process and use the simulation data to improve the optimization model
Wang *et al.* (2011)	✓	✓		To determine the value of collaboration in the supply chain through enhancing business processes from the standpoint of business simulation
Windisch *et al.* (2013)	✓	✓		To provide a methodological framework for the detailed examination of the composition and operation of supply chains for forest fuels in different operational contexts
Mousavi *et al.* (2019)	✓	✓		To develop conceptual models for supply chain planning systems that simulate the order management process in sophisticated semiconductor manufacturing
Schätter and Morelli (2021)	✓	✓		To provide a resilient supply chain in the supply chain risk management field
This study			✓	To reduce the detrimental impact congestion at security checkpoints has on the efficiency of relief aid distribution along the humanitarian supply chain

Hybrid simulation-optimization approach for humanitarian logistics

Author	*Problem type*				*Approach*	*Use of simulation*
	Facility location	*Location–allocation problem*	*Healthcare emergency response*	*Congestion at security checkpoints problem in humanitarian network*		
Sahebjamnia *et al.* (2017)	✓				Rule-based simulation optimization technique	To calculate the performance metrics of the various humanitarian relief chain configurations
Alizadeh *et al.* (2019)	✓				Combining a two-stage stochastic programming model with a realistic simulation model	To estimate the number of casualties and the amount of available transportation capacity
Karatas and Yakıcı (2019)	✓				Combining the classic *p*-median problem location model with a discrete event simulation	To assess the performance of location schemes derived from the deterministic mathematical model
Salehi *et al.* (2019)		✓			Combining a two-stage multiperiod stochastic model with the Monte Carlo simulation model	To appropriately apply and assess the mathematical model
Ghasemi and Khalili-Damghani (2021)		✓			Combining an optimization model for the multiperiod location-allocation inventory problem with enterprise dynamic (ED) simulation	To estimate the mean and variance of demand for relief commodities, numerous earthquake scenarios are designed and tested using a simulation approach
Farahi and Salimifard (2021)			✓		Combining an emergency department's discrete event simulation (DES) model with an optimization model	To design and model emergency department systems and various crisis scenarios
Hatami-Marbini *et al.* (2022)		✓			Combining a dual-objective optimization model with a computer simulation analysis	To find the average ambulance utilization value at stations
Mousavi *et al.* (2022)		✓			A hybrid mathematical-simulative location-allocation model	To estimate medical centers' optimum capacity and simulate how victims will behave at the beginning of the disaster
This study				✓	Combining a linear programming model with business process simulation	To estimate the clearing function, which is subsequently incorporated into the decision-support tool to address congestion in the supply network

Source: Table created by authors

SCP in previous studies was related to commercial SCP. However, our work is unique in that it considers combining the BPS and SCP in the context of humanitarian SCP with the aim of reducing the negative effects of congestion at security checkpoints on the effectiveness of relief aid distribution along the humanitarian supply network. Related studies that concentrated on a hybrid simulation-optimization approach to humanitarian logistics are detailed in the second group of the table. These studies were arranged and categorized based on the type of problem, approaches used and intended use of the simulation. According to the literature, no study has used a hybrid simulation-optimization approach to improve humanitarian logistics performance by handling congestion at security checkpoints, especially in the context of disaster response. Furthermore, our approach is the first to estimate the clearing function, which is subsequently used to alleviate congestion at security checkpoints using the output of the BPS as input data.

3. Research methodology

First, BPM methods are used to improve the process at the KAS security checkpoint, which is used as a real-world case study. The business process model and notation (BPMN) language is used to model the current internal process as well as the TO-BE model. Dumas *et al.* (2018) define BPM as the activities of identifying, designing, implementing, monitoring and analyzing organizational business processes. It is concerned with managing the entire chain of events, activities and decisions that, in the end, add value to the organization and its customers, while also achieving the firm's customer satisfaction goals and objectives (Saragiotis, 2019). These objectives are met by linking management and information technology through methods, techniques and tools for designing, implementing, monitoring and analyzing organizational business processes (Vizzon *et al.*, 2020). Process redesign is an essential stage of the BPM life cycle. Each business process is analyzed during this phase to determine which business activities should be reorganized, automated, incorporated or removed (Gross *et al.*, 2020). Our business process redesign adheres to the reengineering principles proposed by Hammer and Champy (1993).

Subsequently, the hybrid simulation-optimization method is implemented by generating input data for our optimization model using the BPS output of both the AS-IS and TO-BE models. These data were used to calculate the clearing functions of both models. We use the clearing function concept to capture congestion at security checkpoints. We modeled the relationship between truck workload and lead time, that is, the average time spent by a truck processing and waiting. These nonlinear functions express the expected throughput of a capacitated resource as a function of a measure of the work-in-process (WIP) of the resource during that period, which is determined by the resource's average utilization during that period (Graves, 1986; Aouam and Uzsoy, 2015; Aouam *et al.*, 2018). The combination of optimization and simulation, on the other hand, is viewed as a logical way to improve the quality of the supply chain decision support system (Ivanov *et al.* (2022); Clavijo-Buritica *et al.* (2023) by investigating the details provided by the simulation, as well as the capabilities of optimization techniques to find optimal solutions (Figueira and Almada-Lobo, 2014). In this study, a three-phase approach for hybrid simulation-optimization methods was used for the proposed decision-support tool, CFDM. The methodology is depicted in Figure 1 and explained below.

3.1 Phase 1: AS-IS security checkpoint business process model discovery and CFDM clearing function estimation

The first phase involved discovering the process at the security checkpoint, followed by an in-depth AS-IS analysis. This step entails modeling the security checkpoint AS-IS process using the BPMN language. All quantitative data, such as used resources and the probability distribution for the arrival time and task execution time, were extracted from interviews with employees at the security checkpoint. In addition to the direct observation of the process at the checkpoint, additional data were obtained from humanitarian organizations and the private sector, which used the checkpoint on a daily basis. As a quantitative process analysis technique, a BPS model was built to simulate the AS-IS model, execute the process step-by-step, and record each execution step. The results of the simulation include the average security checking process cycle times, average waiting times and resource utilization statistics. The process cycle time and waiting time data are used as input data to estimate the clearing function for the security checkpoint. Finally, the estimation results and supply network data are used as input data for the decision-support tool (CFDM), and the results are measured based on key performance indicators (KPIs) such as average inventory at warehouses and distribution centers, average WIP at security checkpoints, average backordering cost and average cycle time at the security checkpoint.

3.2 Phase 2: redesign the AS-IS security checkpoint business process model based on BPR principles

In the second phase, the AS-IS model was reengineered using the BPR principles proposed by Hammer and Champy (1993). First, we analyzed the AS-IS model and identified the activities to be redesigned based on Pareto analysis and expert viewpoints in terms of the average waiting time. Second, we propose six scenarios for the process at the security checkpoint during this phase. These scenarios were created in collaboration with humanitarian organizations, Palestinian logistical service enterprises, the Palestinian Authority and daily drivers passing through the KAS security checkpoint. The result of this phase is the TO-BE model for the security checkpoint process.

3.3 Phase 3: TO-BE simulation results analysis and clearing function estimation

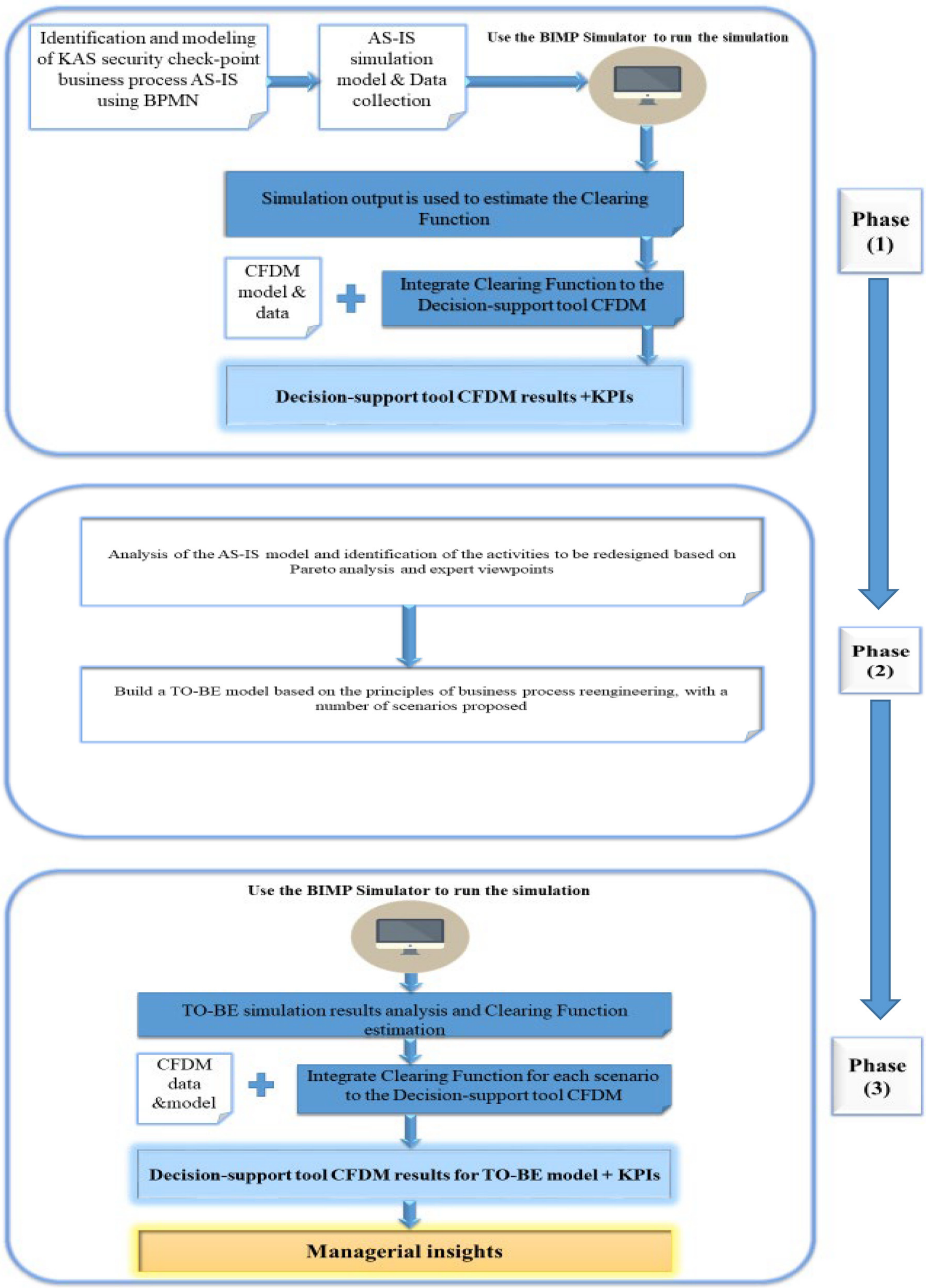
In this final phase, a BPS model is developed for the TO-BE process with various scenarios to assess their performance in terms of the average security-checking process cycle times and average waiting times. Similar to Phase 1, the process cycle time and waiting time data were used as input data to estimate the clearing function for each scenario. The decision support tool (CFDM) is then run using the estimation results and supply network data as input data, and the outcomes are evaluated using KPIs, such as the average inventory at warehouses and distribution centers, average WIP at security checkpoints, average cost of backordering and average cycle time at security checkpoints. The best scenario was selected after numerous scenarios were evaluated based on the selected KPIs. Finally, the best-case scenario of the TO-BE model was compared with the outcomes of the AS-IS model based on the previous KPIs to explain the difference between the two outcomes.

4. Demonstration of the method using case study

4.1 Case study

The KAS security checkpoint is considered extremely important for the lives of the Gaza Strip's civilian population. This checkpoint is located south of the Gaza Strip, as illustrated in Figure 2. The KAS security checkpoint is Gaza's main commercial border security checkpoint and the only commercial checkpoint with Israel. It handles 80% or more of the goods entering the strip. In addition, this was the only point of entry for humanitarian aid from Israel into the Gaza Strip. The KAS security checkpoint was established in 2005 as a checkpoint for the entry of goods and humanitarian aid from Israel, the West Bank and other countries into Gaza. The Israeli government controls border crossing by deciding what can and cannot cross, how much of it can cross and when it can cross (Logistics Cluster, 2014; Gisha, 2020).

Figure 1 Hybrid simulation-optimization method



Source: Figure created by authors

Figure 2 KAS security checkpoint location

Source: Figure created by authors

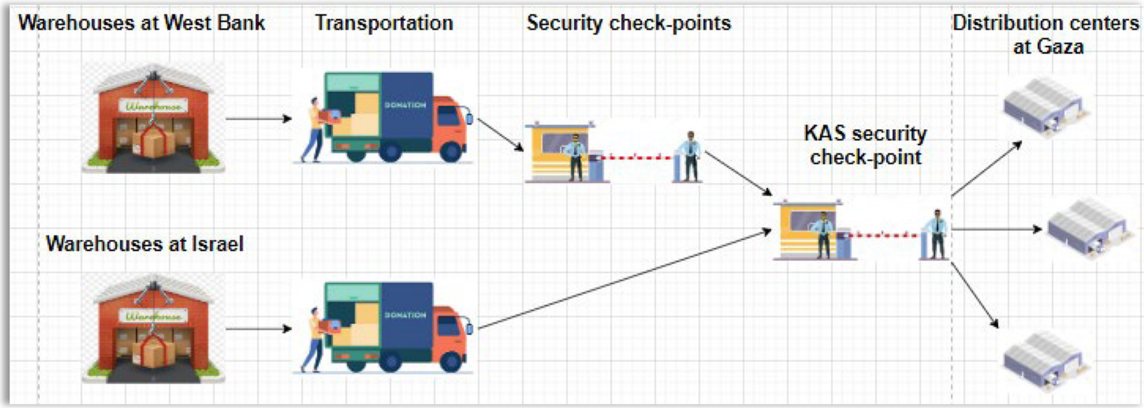
From Sunday to Saturday, the KAS security checkpoint is open five days a week. Trucks carrying goods bound for Gaza can enter the Israeli side of the crossing between 6:00 A.M. and 3:00 P.M. and work inside this crossing continues until sundown. The crossing was designed and built such that trucks on both sides of the border–Israel and Palestine–would not come into direct contact. The KAS security checkpoint extends over 60 hectare. On the Palestinian side, there are 20 hectare. On the Israeli side, there are 40 hectare. The area was divided into 11 outdoor cells on the Israeli side. Each cell covered approximately 1 hectare. Some cells are dedicated to screening specific types of products such as building materials or cattle. Each cell can accommodate approximately 20 trucks simultaneously (Gisha).

Although the situation in Gaza remains dire, progress in discussions on upgrading the KAS security checkpoint is encouraging (Quartet, 2019, New York). The KAS security checkpoint upgrade project is expected to reduce the damage to perishable goods by an estimated 60% by creating a shaded area for goods entering and exiting Gaza. The progress of the project slowed owing to the escalation in May 2021. The Netherlands is currently making a leading effort to re-launch this project (Quartet, 2021). The goal of this project was not to reduce the processing cycle time or the congestion caused by existing procedures. In contrast, our efforts will contribute to the enhancement of the current project as well as any future plans to improve the situation at the KAS security checkpoint by focusing on congestion issues and reducing their impact on the delivery lead time of goods to the Gaza Strip.

4.2 Problem description

Security checkpoints are regarded as the only official gates through which countries can control the flow of commodities in accordance with their security and safety standards. Generally, these safety standards are tightened through security checking processes and complex control procedures, which are sources of congestion and cause delays in the transportation of goods to their final destination. Security checkpoints in Palestine are a major cause of delays in the flow of goods between the West Bank, Gaza Strip, and Israel. For example, the KAS security checkpoint is the only entry point for goods from Israel into the Gaza Strip, as illustrated in Figure 3. First, the Israeli authorities used the KAS security checkpoint to restrict the entry of certain goods into Gaza, including building materials, medical supplies and WASH spare parts. To deal with these constraints, intensive collaboration with various authorities was required, which caused delays. In addition, owing to the pressure at this security checkpoint, the procedures for prioritizing cargo have changed, making it difficult for trucks to enter Gaza on a daily basis. Consequently, delays in both commercial and humanitarian cargo access to the final destination in the Gaza Strip have increased (UNCTAD, 2020; OCHA, 2023b). This motivated us, as researchers at Ghent University to propose a new model based on re-engineering the

Figure 3 Goods flow through the distribution network to the KAS security checkpoint



Source: Figure created by authors

processes at the KAS security checkpoint to improve the efficiency of the security checking process. As a result, the delivery lead-time of goods shipped to the Gaza Strip can be reduced. This effort is made possible by a collaborative effort with the Palestinian Authority, humanitarian organizations involved in the relief field and private transportation companies in Palestine to suggest viable strategies and techniques to improve the processes at this security checkpoint.

4.3 The AS-IS security checkpoint business process model creation and the CFDM's clearing function estimation

Phase one is covered in this part. An AS-IS model was created using BPMN language to simulate the process at the KAS security checkpoint. Then, the simulation output was used as input data to estimate the clearing function for the KAS security checkpoint, and subsequently, it was used to run the proposed decision-support tool, CFDM.

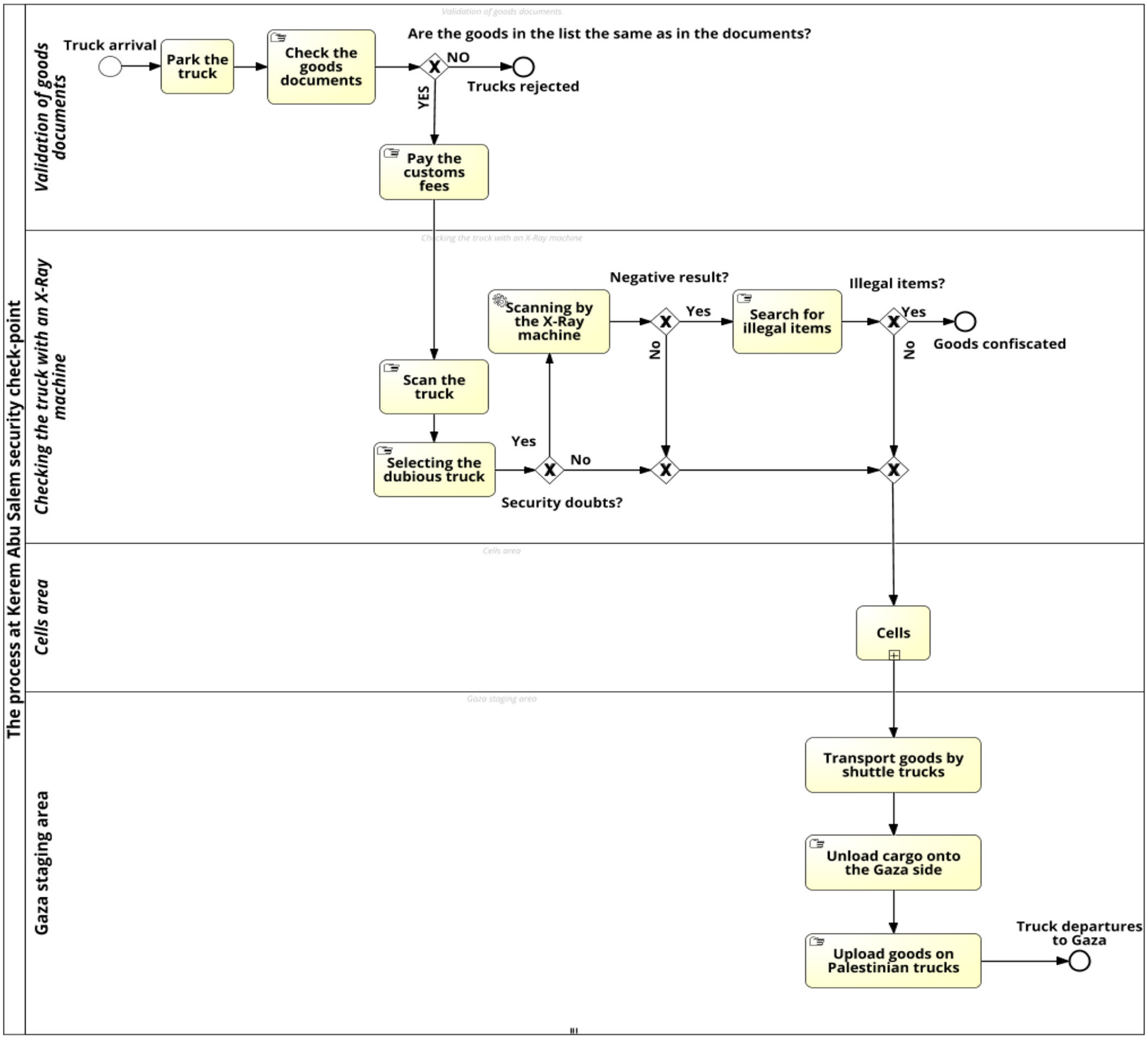
4.3.1 Identification and modeling of KAS security checkpoint business process AS-IS using BPMN

The core process at the KAS security checkpoint is modeled using a BPMN language. The crossing is divided into two parts: the first is located on the Israeli side and the second on the Palestinian side. This means that there was no direct contact between trucks from the Israeli side and those from the Gaza Strip. The Israeli Ministry of Defense's Crossing Authority manages the Israeli side of the border security checkpoint, which is subcontracted to a private Israeli security company. This private Israeli company hired additional contract workers to operate forklifts at the checkpoint. In general, Israeli trucks enter the cells, unload goods, and leave. Then, the crossing trucks and forklifts enter the cells and transfer commodities to the cells on the Palestinian side. A private Israeli company hired private Palestinian transport companies to operate on the Gaza side of the KAS security checkpoint. All goods except aggregates and fuel were transported by a Palestinian company. Another Palestinian company specializes in the transportation of gravel and other aggregates (Gisha, 2020). Once these trucks unload goods and leave the cells, trucks from Gaza gather the goods and set them off for their destination.

Each truck transporting a product must complete a number of activities at the KAS security checkpoint, as shown in Figure 4, which depicts the process flow of trucks carrying goods at this security checkpoint. The process at the security checkpoint is divided into four lanes: "validation of goods documents," "checking the truck with an X-ray machine," "unloading cargo into the cells area" and "Gaza staging area." Each lane has a specific task. The first task in the validation of goods document lanes is to park good-laden trucks in a yard near the entrance gates to the security checkpoint. The truck drivers wait in line to check in with their goods documents at the Israeli Authority Office. Trucks that did not pass through the crossing at 3:00 had to wait until the following day. Drivers stop their trucks at the entry gate and walk over to check their truck numbers on the board, which displays the number of trucks permitted to enter a security checkpoint. In addition, they must obtain a document called "Taom," which relates to their cargo and includes the type and size of these goods. The second step is to check the documents of the goods. The goods must be approved by the Israel Defense Forces and Coordination of Government Activities in the Territories (COGAT) by checking the Taom document and investigating whether the goods' type and size match what is written in the document. If an error occurs in the matching process, the truck stops and returns to its original location. Otherwise, the truck continues to the next security-checking activity steps. The final task in this lane is to pay customs, which is approximately $200 per truck, and other fees in a designated window. Eight employees performed in this lane.

The truck in the next lane is checked using an X-ray machine. First, a security officer must randomly test the trucks. This task was accomplished using dogs and a hand scanner machine. Dogs rummage the contents of trucks. If security concerns exist, the truck is directed to an X-ray machine. This path is taken by 15% of the trucks on average. Each truck visited the X-ray machine for 15 min. If the security team suspects illegal items in the cargo, they use a forklift to rearrange the load on the truck, which takes approximately 30 min; if these items are indeed illegitimate, trucks are confiscated by the Israeli side; otherwise, the truck continues with the procedures and moves to the area of the cells. This lane had eight employees who executed tasks.

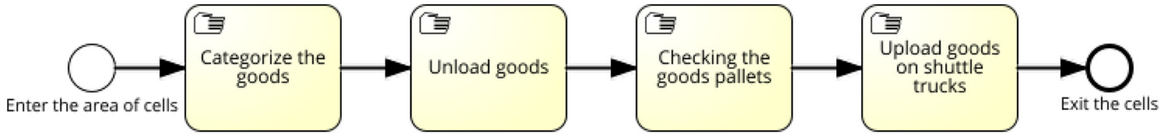
Figure 4 Process flow of trucks loaded with goods through the KAS security checkpoint



Source: Figure created by authors

The third lane of the security checkpoint is the cell area. Trucks enter the cell area (large rooms) where the cargo is unloaded. The cell area was divided into 11 sections. Trucks that pass all previous security-checking activities are unloaded with the cargo in these cells. Each cell can simultaneously absorb approximately 20 trucks at the same time. The goods are offloaded in that cell until the cell capacity is reached and are subject to the last inspection. The staging area doors to Gaza opened after that, which was the start of the last lane. The goods were uploaded to shuttle trucks and transported from the cells to the Gaza stage area. These trucks never leave the crossing and are always present in the restricted zone between Israel and Gaza's staging areas. The shuttle trucks begin their journey to the Gaza stage at the cell between 6:00 A.M. and 3:00 P.M. The Gaza staging area is open to goods collection between 3:00 and 6:00 P.M. The goods deposited by shuttle trucks are collected by forklifts and uploaded to Palestinian trucks aligned along the Gaza access route. Finally, Palestinian trucks transported goods to Gaza via the Philadelphia Corridor. This lane employed 20 individuals to complete the tasks. When trucks arrive at the cell area, they follow a specific procedure, which is modeled as a subprocess in Figure 5 below. First, when trucks enter a cell, a security guard categorizes the goods on the trucks as foodstuffs (especially cold foodstuffs) or non-foodstuffs. Goods are classified by inspecting the Taom of the truck taxes. The goods are then offloaded from the truck. The next task is for a security guard to walk between the goods pallets on the cell floor carrying a small scan machine.

Figure 5 The subprocess that occurs in the cell area



Source: Figure created by authors

Subsequently, the goods uploaded by forklifts on shuttle trucks are transported to the Palestinian side.

4.3.2 AS-IS simulation model and data collection

A discrete-event simulation is used in this section to simulate the AS-IS model of the internal process at the KAS security checkpoint. We provide the simulation inputs based on the data in Tables 2–4. Data on the internal processes of the KAS security checkpoint were gathered from a variety of sources (the UN cluster logistics database, the General Administration of Borders and Crossings/the Palestinian side, Gisha, Palestinian logistics companies and interviews with workers and drivers at this crossing). Table 2 lists the probability distribution of the tasks at the KAS security checkpoint. Table 3 depicts the decision gateways through which employees make decisions regarding goods entering the security checkpoint. Finally, Table 4 lists the number of employees assigned to each section of the security checkpoint. According to the data, the KAS security checkpoint works 9 h per day, five working days per week or 45 h per week. Trucks arrive only during these 45 h, and security checkpoint operators work only during these 45 h. The current scenario (AS-IS) has an arrival rate of approximately 2,000 trucks per week, which is equal to approximately one truck every 3 min (this is the inter-arrival time). Because the trucks arriving at the KAS security checkpoint are more random in nature, with trucks arriving independently and at a steady average rate, we used an exponential distribution for the inter-arrival time. The processing time for each activity is approximately a given average inside this security checkpoint. The deviation around this range was approximately symmetric, implying that there was an equal chance that the actual processing time would fall

Table 3 Probability of decision gateways

Gateway	Decision	Probability (%)
Are the goods in the list the same as in the documents?	*No*	*10.00*
	Yes	*90.00*
Security doubts?	*No*	*85.00*
	Yes	*15.00*
Negative result?	*No*	*60.00*
	Yes	*40.00*
Illegal items?	*No*	*80.00*
	Yes	*20.00*

Source: Table created by authors

Table 4 Employees assigned to each section at a KAS security checkpoint

Role (lanes)	Work schedules
Validation of goods documents	*10 employees*
Checking the truck with an X-ray machine	*9 employees*
Cells area	*14 employees*
Gaza staging area	*10 employees*

Source: Table created by authors

Table 2 Probability distribution data for existing tasks at the KAS security checkpoint

Task	Shapiro–Wilk ($W_{Calculated}$)	Reference value $W_{Critical}$	Execution time (min)
Park the truck	*0.978*	*0.94*	*Normal(15,5)*
Check the goods documents	*0.965*	*0.94*	*Normal(5,2)*
Pay the customs fees	*0.966*	*0.94*	*Normal(8,2)*
Scan the truck	*0.972*	*0.94*	*Normal(10,6)*
Selecting the dubious truck	*0.975*	*0.94*	*Normal(5,2)*
Scanning by the X-ray machine	*0.966*	*0.94*	*Normal(10,2)*
Search for illegal items	*0.974*	*0.94*	*Normal(8,2)*
Transport goods by shuttle trucks	*0.985*	*0.94*	*Normal(10,5)*
Unload goods into Gaza side	*0.962*	*0.94*	*Normal(15,5)*
Load goods on Palestinian trucks	*0.975*	*0.94*	*Normal(15,5)*
Cells area (subprocess)	*0.953*	*0.94*	*Normal(45,10)*
Categorize the goods	*0.988*	*0.94*	*Normal(7,3)*
Unload goods at the cells	***0.984***	*0.94*	*Normal(15,5)*
Checking the goods pallets	***0.991***	*0.94*	*Normal(8,5)*
Upload goods on shuttle trucks	***0.973***	*0.94*	*Normal(15,5)*
Inter-arrival time			*Exponential(3)*

Source: Table created by authors

or increase above the mean. The normality of the processing time data was examined using the Shapiro–Wilk test. We collected data on the average number of trucks permitted to pass through the checkpoint each day (approximately 40 trucks) and used the data to calculate the processing time for each checkpoint activity. The test findings are shown in Table 2, which compares the calculated W with the critical W based on $p > 0.05$ that are obtained from the Shapiro–Wilk table (Shapiro and Wilk, 1965). The normality of the data was rejected if the calculated W was less than the crucial W. Consequently, we conclude that it is appropriate to calculate the processing duration for each task using a normal distribution. The simulations were performed for one week.

Before running the AS-IS simulation model, the number of replicates required to ensure reliability of the results was estimated. The simulation model was used to recreate the configuration for five working days at the security checkpoint. The simulation model was manually ran 20 times to evaluate the validity of the results, namely, the average security checking process cycle time, average waiting time and average resource utilization. Starting with replicate 2, the mean $\overline{X}$ and variance σ^2 of each output observed were calculated, as well as the confidence interval at $p = 95\%$ ($\alpha = 0.05$) of the output as a function of the number of replicates n. For the computation of the confidence interval, the following formula was used (Rinaldi *et al.*, 2015):

$$CI - lower = \overline{X} - \left(\frac{\alpha}{2}, n-1\right) * \frac{\sigma}{\sqrt{n}} \quad (1)$$

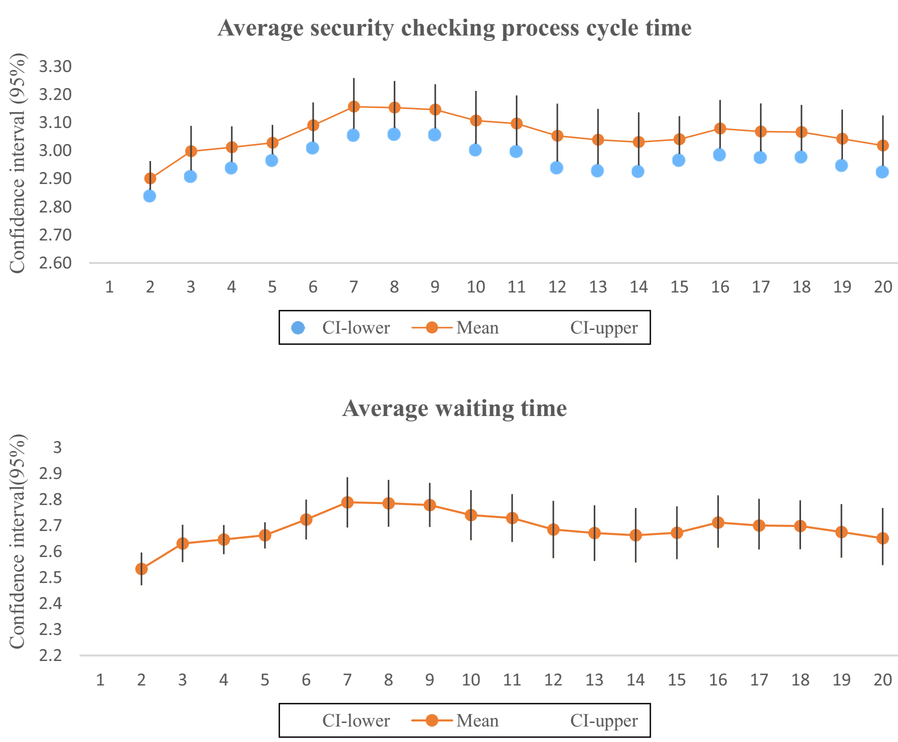
$$CI - upper = \overline{X} + T\left(\frac{\alpha}{2}, n-1\right) * \frac{\sigma}{\sqrt{n}} \quad (2)$$

where $CI - lower$ and $CI - upper$ denote the lower and upper bounds of the result's confidence interval, respectively, and $T\left(\frac{\alpha}{2}, n-1\right)$ is the T-distribution with $n-1$ degrees of freedom. Figure 6 shows the trend of the confidence interval as a function of the number of replicates. Figure 6 shows that the simulation results were sufficiently stable after 12 replicates, which was chosen as the number of runs for the subsequent scenario analyses. Finally, before evaluating the performance using the simulation model, we tested its accuracy in comparison to the real situation by presenting the results (AS-IS model) on the drivers who crossed the checkpoint on a daily basis, as well as the workers there and one of the Palestinian companies that operated at this security checkpoint. They regarded the simulation results as valid. We were unable to reveal the names of the Palestinian companies because of confidentiality and privacy concerns.

4.3.3 *Simulation output of AS-IS model and clearing function estimation*

4.3.3.1 Simulation output of AS-IS model. The BIMP simulator [1] was used to simulate the business process models and obtain their statistics. The BIMP simulator was chosen because it provides a wide range of distribution probability options that broaden the configuration space (Estrada-Torres *et al.*, 2021). This simulator accepts the BPMN process model as input. The validation of goods documents, checking the truck with an X-ray machine, the cell area, and the Gaza staging area were resource

Figure 6 Confidence interval for the simulation results as a function of the number of replicates



Source: Figure created by authors

lanes. We assigned tasks to the resource lanes based on the current situation. The cycle times from the AS-IS model were used as inputs for the simulation. When the simulation is run, the BIMP simulator produces the following results, as shown in Table 5. The average cycle time (excluding off-timetable hours) was approximately 3.05 h, with a maximum observed cycle time of approximately 5.9 h. Furthermore, the average wait time was 2.68 h, with a maximum observed wait time of 5.475 h. In other words, resources are overutilized, resulting in long cycle and waiting times. This overburdened resource utilization represents the processes at the KAS security checkpoint, which results in congestion at this security checkpoint most of the time during normal working hours.

4.3.3.2 Clearing function estimation. When security checkpoints are congested, nonlinear CFs can be used to model the relationship between the truck output flow (or throughput) and the workload at these checkpoints during the planning period. Congestion effects are captured by considering the relationship between lead time (i.e. the average time spent waiting and processing a truck) and the total workload in WIP composed of commercial and humanitarian trucks. The concept of CFs is borrowed from the production literature, where CFs are used to represent the expected throughput of a capacitated resource (machine, work center or factory) over a given period as a function of some measure of the WIP level at

Table 5 Performance measure for the current processes at the Kerem Abu Salem checkpoint

Performance measure	Average value
Validation of goods documents Utilization (%)	74
Checking the truck with an X-Ray machine Utilization (%)	50
Cells area utilization (%)	87
Gaza staging area utilization (%)	74
Automated service utilization (%)	24
Cycle time (hour per day)	3.05
Waiting time (hour per day)	2.68

Source: Table created by authors

this resource over that period, which is determined by the resource's average utilization over that period (Graves, 1986; Karmarkar, 1989).

A commonly used clearing function was proposed by Srinivasan *et al.* (1988) and is given by:

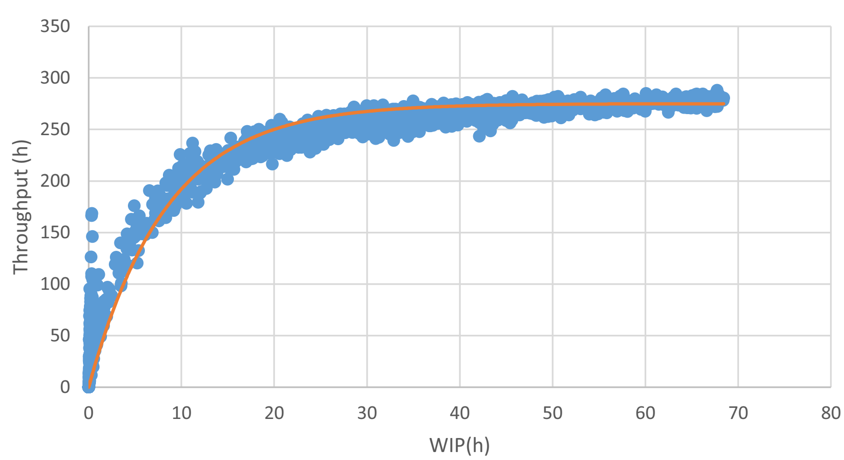
$$CF(WIP) = C\left(1 - e^{-C'.WIP}\right) \quad (1)$$

where C is the maximum capacity and C' is the curvature of the CF. To estimate the clearing function at the Kerem Abu Salem security checkpoint, we generate average WIP versus average cycle time data from the simulation output of the AS-IS business process model. It should be noted that the clearing functions for other security checkpoints in the proposed CFDM model were estimated in a previous study, and we used the same estimation results. Throughput is computed based on Little's law as the average WIP in hours (the average time spent by a truck at the security checkpoint (in processing and waiting) divided by the average cycle time (in hours). The throughput and WIP were both measured in hours and are represented by the y- and x-axes of our clearing function, respectively. We collected the WIP and Throughput statistics from a one-working-week simulation run with 400 trucks per day on average over five days at the security checkpoint (9 h × 5 d = 45 h). As a result, we have a [WIP, TH] dataset for the KAS security checkpoint that contains 2000 data points (400 trucks per day × 5 days). The workload of the WIP versus the throughput per working day are plotted as shown in Figure 7 (scatter points).

A nonlinear clearing function is given by equation (1), that is, of the form $CF(WIP) = C(1 - e^{-C'.WIP})$, is then fitted to the data, and the resulting nonlinear function for the security checkpoint are represented in Figure 7. The maximum capacity C for the security checkpoint is the maximum possible throughput, which is determined from empirical data, while C' is estimated using the least sum of squares method. The estimated values of capacity C and CF curvature C' for the KAS security checkpoint are listed in Table 6.

Similar to Kefeli *et al.* (2011), the estimated CF at the security checkpoint is approximated using an outer linearization with eight segments. The slopes α_l^k and intercepts β_l^k for the

Figure 7 Estimation of CFs at the KAS security checkpoint



Source: Figure created by authors

Table 6 Estimated parameters of CF at the KAS security checkpoint

Security checkpoint	Capacity *C* (in hours/day)	CF curvature *C′*
Kerem Abu Salem	275	0.12

Source: Table created by authors

security checkpoint are given in in Table 7. The last segment of the clearing function corresponds to the capacity of the corresponding checkpoint, with $\alpha_8^k = 0$ and $\beta_8^k = C$.

4.3.4 Data and modeling for CFDM and integrating the clearing function into this tool

In this study, data were collected from various organizations to estimate the parameters of the CFDM, as illustrated in Appendix. The following sources were used in this study. First, the Logistics Cluster database (www.logcluster.org) was used to calculate the transportation costs between different locations. The second is Israel's Crossing Point Authority (www.mod.gov.il/). The third was the data base of the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA) (www.ochaopt.org/data) and the United Nations Relief and Works Agency. This source provided us with the number of commercial and humanitarian trucks at each security checkpoint, the demand at distribution centers and the holding and backordering costs at warehouses and distribution centers. Finally, from the official website of the COGAT (www.gov.il/), the capacity of security checkpoints was estimated using this data.

The established plan aims to ship relief items, as a single aggregate item, from warehouses in the West Bank and Israel to distribution centers in the Gaza Strip. In a previous work, Rezeq *et al.* (2023) used a CFDM decision tool to establish plans for multiple products. Human food products, nonedible consumables and medical supplies were among the relief aid supplied by the local community, international donors and the government sector and distributed through the supply network under this plan. Figure 8 shows a relief aid distribution network.

CFDM formulation

The following notations are used throughout the paper.

Sets

- ***M*** Set of warehouses, indexed by *m*
- ***D*** Set of distribution centers, indexed by *d*
- ***K*** Set of security checkpoints, indexed by *k*
- ***N*** Set of all stages (nodes), indexed by *n*
- ***A*** Set of arcs, representing flows between stages
- ***L*** Set of linear segments to approximate the clearing function, indexed by *l*

Decision variables

- $X_t^{nn'}$ Number of trucks sent from stage *n* to stage *n′* in period *t*
- I_t^m Inventory (in number of truck loads) at warehouse *m* at the end of period *t*
- S_t^m Supply (in number of truck loads) at warehouse *m* in period *t*
- I_t^d Inventory (in number of truck loads) at distribution center *d* at the end of period *t*
- B_t^d Backorders (in number of truck loads) at distribution center *d* at the end of period *t*
- W_t^k Workload WIP (in hours) of trucks at security checkpoint *k* in period *t*

Table 7 Piecewise linear approximation of CF at the security checkpoint

	KAS checkpoint	
Segment	α	β
1	4.16	2.7
2	2.02	53.169
3	0.96	128.37
4	0.47	165.54
5	0.20	216.8
6	0.17	229.9
7	0.039	255.2
8	0	275

Source: Table created by authors

Parameters

- $c_t^{nn'}$ Transportation cost per truck of item *p* sent from stage *n* to stage *n′* in period *t*
- h_t^m Holding cost of item *p* at warehouse *m* at in period *t* (per truck load per period)
- s_t^m Supply cost of item *p* at warehouse *m* in period *t* (per truck load)
- h_t^d Holding cost of item *p* at distribution center *d* at the end of period *t* (per truck load per period)
- b_t^d Backordering cost of item *p* at distribution center *d* at the end of period *t* (per truck load per period)
- q_t^d Demand of item *p* at distribution center *d* at the end of period *t* (per truck load)
- ω_t^k WIP holding cost item *p* at security checkpoint *k* in period *t* (per hour per period)
- α_l^k CF slope of line segment *l* at security checkpoint *k*
- β_l^k CF intercept of line segment *l* at security checkpoint *k*
- ξ^k Processing time at security checkpoint *k* in period *t* (in hours per truck)
- f_t^k Regular workload (commercial trucks flow in hours) at security checkpoint *k* in period *t*

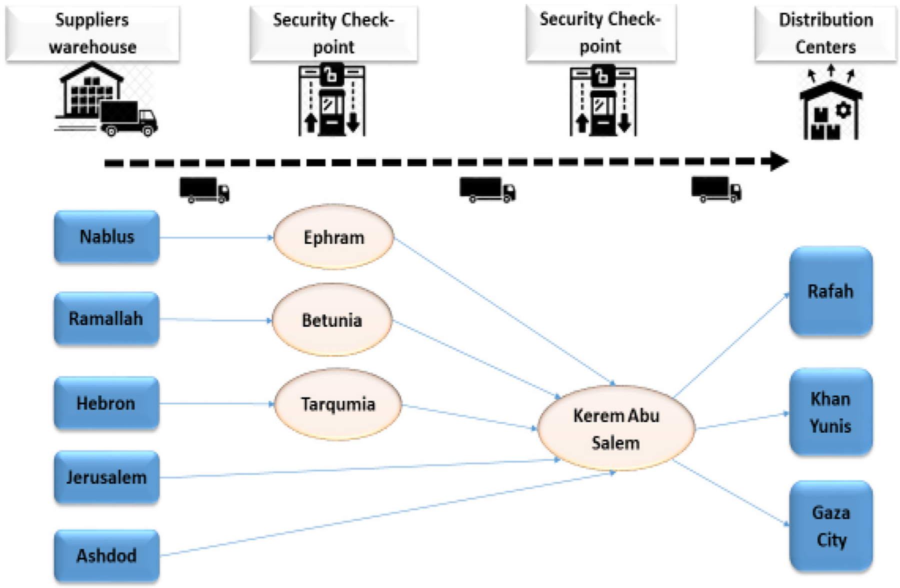
The flow capacity at security checkpoint *k* can be formulated using a nonlinear CF of the form (1) as follows:

$$\sum_{(k,n)\in A} \xi^k X_t^{kn} \le CF\left(W_{t-1}^k + \sum_{(k,n')\in A} \xi^k X_t^{kn'} + f_t^k\right) \quad (2)$$

The left-hand side of constraint (2) $\left(\sum_{(k,n)\in A}\xi^k X_t^{kn}\right)$ is the total throughput (in hours) of workload of trucks leaving for multiple destinations *n*. The total workload in WIP at checkpoint *k* in period *t* is $W_{t-1}^k + \sum_{(k,n')\in A}\xi^k X_t^{kn'} + f_t^k$, which includes the total workload from the previous period plus the incoming workload from multiple origins *n*', in addition to workload in commercial trucks f_t^k (in hours). Following Asmundsson *et al.* (2009), equation (2) can be linearized using multiple segments by introducing the following set of linear constraints:

$$\sum_{(k,n)\in A} \xi^k X_t^{kn} \le \alpha_l^k\left(W_{t-1}^k + \sum_{(k,n')\in A} \xi^k X_t^{kn'} + f_t^k\right) + \beta_l^k \quad \forall l \in L \quad (3)$$

Figure 8 Humanitarian distribution network in Palestine



Source: Figure created by authors

The CFDM is formulated as follows:

$$\min \sum_{t\in T}\left(\sum_{(n,n')\in A} c_t^{nn'} X_t^{nn'} + \sum_{m\in M}\left(s_t^m S_t^m + h_t^m I_t^m\right) + \sum_{k\in K}\omega_t^k W_t^k + \sum_{d\in D}\left(h_t^d I_t^d + b_t^d B_t^d\right)\right) \quad (4)$$

$$\text{s.t.} \quad I_t^m = I_{t-1}^m + S_t^m - \sum_{(m,n)\in A} X_t^{mn} \quad \forall m \in M, t \in T \quad (5)$$

$$I_t^d - B_t^d = I_{t-1}^d - B_{t-1}^d + \sum_{(n,d)\in A} X_t^{nd} - q_t^d \quad \forall d \in D, t \in T \quad (6)$$

$$W_t^k = W_{t-1}^k + f_t^k + \sum_{(n,k)\in A} \xi^k X_t^{nk} - \sum_{(k,n')\in A} \xi^k X_t^{kn'} \quad \forall k \in K, t \in T \quad (7)$$

$$\sum_{(k,n)\in A} \xi^k X_t^{kn} \le \alpha_l^k \left(W_{t-1}^k + \sum_{(k,n')\in A} \xi^k X_t^{kn'} + f_t^k\right) + \beta_l^k \quad \forall l \in L, t \in T, k \in K \quad (8)$$

$$X_t^{nn'}, I_t^m, S_t^m, I_t^d, B_t^d, W_t^k \ge 0 \quad \forall k \in K, n, n' \in N, t \in T \quad (9)$$

Objective function (4) minimizes the total distribution cost of the humanitarian supply network. It includes the cost of transportation between stages (first term), the cost of supply and inventory holding at warehouses (second term), the WIP holding cost (third term) and the cost of holding inventory and shortage at distribution centers (fourth term). Constraints (5)–(7) are the inventory balance constraints at the warehouses, distribution centers and security checkpoints, respectively. Constraint (8) models the workload output at the security checkpoints using the clearing function. Constraint (9) ensures the non-negativity of the decision variables. The WIP holding cost represents the cost of waiting at the security checkpoints, which includes driver wages and parking charges. For example, in the case of the GAZA war, the WIP holding cost was estimated by the Logistics Cluster and the UNOCHA. These costs include overnight parking charges, and trucks arriving late at security checkpoints are forced to wait until the next day.

4.3.5 Results of CFDM and KPIs

We used laptop with 8 GB RAM and Intel® i5 - 8250U CPU@ 1.6 GHz to run our experiments. The HDP was implemented using the commercial software GAMS 28.2.0, and the corresponding problem instances were solved using CPLEX 12.9.0.0 solver. Table 8 shows the distribution model's KPIs after applying the CFDM to the Palestinian supply chain case study for one working week (five working days). The total cost of item distribution (commercial and humanitarian) was $2.54m. The average truck load from humanitarian warehouses is 17 trucks per day, and the average relief truck backorders are 2.8 trucks per day at relief distribution centers (demand points). The average lead-time for trucks per day was 2.6 h. The average cycle time is equal to the average WIP divided by the average throughput, based on Little's law. The

Table 8 Performance measures for the CFDM for one working week

Total cost ($)	**$2,544,365**
Average inventory at warehouses (truckload)	17
Average inventory at distribution centers (truckload)	17
Average WIP at security checkpoints (hour)	208
Average backordering cost (truck per day)	2.8
Average cycle time at security checkpoint (hour)	2.6

Source: Table created by authors

average cycle time is the amount of time taken from the arrival of the relief truck at the security checkpoint to its departure. Thus, the security checkpoint had a workload of 116 h.

4.4 Redesign the AS-IS security checkpoint business process model based on BPR principles

This section explains Phase 2, which involves reengineering the AS-IS model in accordance with the principles of BPR proposed by Hammer and Champy (1993). Initially, we assessed the AS-IS model using simulation results and identified the tasks that need to be modified using Pareto analysis and professional opinions regarding the average waiting time. The process at the KAS security checkpoint in this phase is proposed for six possible situations. The TO-BE model for the KAS security checkpoint process is the end product of this phase.

4.4.1 Analysis of the AS-IS model and selection of the activities to be redesigned based on Pareto analysis and expert viewpoints

To identify activities that significantly increase the average waiting time at the KAS security checkpoint, we analyzed the AS-IS simulation model findings in this section in terms of the average waiting time. This analysis was developed using the Pareto analysis, in which the goal of the Pareto analysis is to determine which causal factors of a problem should be prioritized (Dumas *et al.*, 2018). Based on the Pareto analysis, we identified the activities that could result in long wait times and delays and developed alternative solutions for these activities as scenarios. Furthermore, humanitarian organizations, Palestinian logistical service enterprises, the Palestinian Authority and drivers who passed through the KAS security checkpoint daily were involved in the redesign process and scenario development.

In this section, the average waiting time for each activity to be evaluated is first defined and all relevant activities that contribute to the waiting time are identified. Third, a numerical value was assigned to each activity using the selected metric. Finally, we organized the activities according to the selected metric (from the highest to lowest impact) and created the Pareto chart depicted in Figure 9, which has two parts:

1 a bar chart with each bar representing the activity and the height of the bar corresponding to the impact of the task; and
2 a curve showing the activities' cumulative impact.

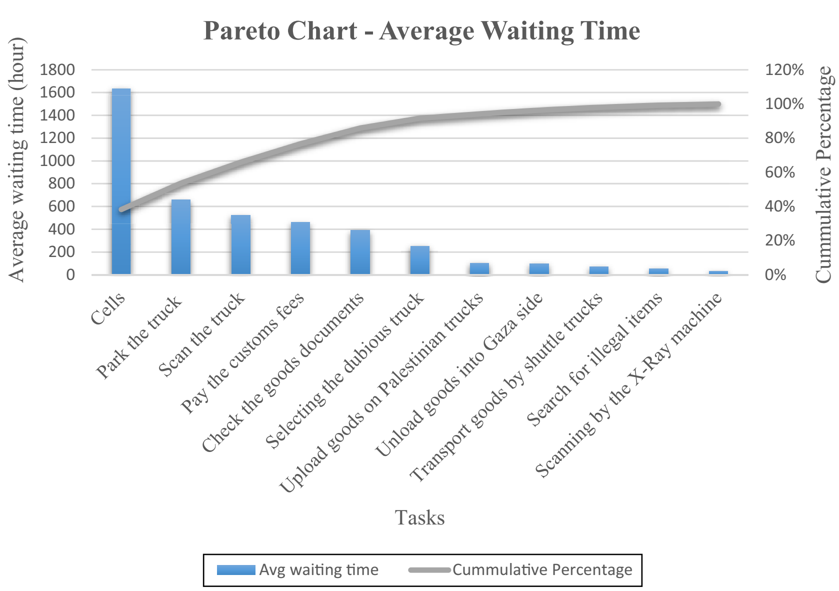
Based on Pareto analysis and the perspectives of humanitarian organizations, Palestinian logistical service enterprises, the Palestinian Authority and drivers who regularly pass through the KAS security checkpoint and participate in the redesign process, we discovered that tasks such as "Cells," "Park the truck," "Scan the truck," "Pay the customs fees" and "Check the goods documents" contribute to truck delays. These tasks were used in the redesign process, and the proposed scenarios were based on the analysis results.

4.4.2 Build a TO-BE model based on the principles of BPR, with a number of scenarios proposed

This section discusses six possible redesign scenarios. Our re-design steps are based on the principles of BPR proposed by Hammer and Champy (1993), as Table 9 explains. An increase in the number of entrance gates is suggested at the border security checkpoint. All scenarios were created based on the baseline model's fundamental inefficiencies: unbalanced resource use, long wait times at the entrance gates and waste time created by inefficient internal processes.

4.4.2.1 Scenario 1: using an electronic queue management system at the entrance gates at the checkpoint. The KAS security checkpoint electronic queue management system was used to prevent the formation of lengthy queues for trucks waiting to enter the inspection zone. The driver can take the ticket and move his truck to the assigned parking area while the line moves and waits for his turn, rather than standing in line, causing congestion at the gates of the check-entrance points. To cut down on waiting times and minimize congestion, we proposed

Figure 9 Pareto chart of the average waiting time for each task at the KAS security checkpoint



Source: Figure created by authors

Table 9 Redesign of the KAS security checkpoint process based on BPR principles

Principles of business process reengineering (Hammer and Champy, 1993)	Our redesign steps are based on BPR principles
Organize around outcomes rather than tasks	• Without affecting the security protocols, we identified the desired goals for the KAS security checkpoint process to improve the security processing and reduce the waiting times at the entrance gates • Instead of just completing specific activities at this security checkpoint, we concentrated on attaining these desired goals when we designed the process
Perform the process with those who will be using the process's output	• Palestinian logistics companies, humanitarian organizations (local and international), and the Palestinian border and passage authority have all taken an active role in offering valuable suggestions for the process redesign
Incorporate information processing work into the actual work that generates the information	• We investigated the information requirements for the KAS security checkpoint, including the necessity to verify documents for drivers, commodities and customs • We attempt to simplified the process and reduce duplication and delays by integrating information processing activities into the work being done at the KAS security checkpoint
Connect parallel activities rather than integrating their outcomes	• We identified parallel activities that take place concurrent at the KAS security checkpoint, such as scanning the truck and selecting the dubious truck • To facilitate the efficient flow of work, we simplify these activities by putting out fresh concepts and IT systems that perform this function
Consider geographically dispersed resources to be centralized	• According to this principle, the KAS security checkpoint is located in one location, and since activities and information are already standardized and centrally located, there are no geographically dispersed resources
Put the decision point where the work is done, and incorporate control into the process	• We assume that decision-making is decentralized, giving KAS security checkpoint staff who are directly performing the work the ability to make decisions and have control over the procedure within the established security regulations and protocols
Capture data only once and at the source	• To accurately, quickly, and freshly record pertinent information (such as activity details and activity processing time), we designed the process in accordance with the actual procedure at this security checkpoint, which we gained from interviews with the staff there and our observations when we visited this security checkpoint

Source: Table created by authors

this mechanism for the "park the truck" activity, which takes on average 15 min. This technology replaces the manual process for scheduling the time required to pass through the checkpoints.

4.4.2.2 Scenario 2: using IT applications to transfer invoices and documents. Because of the time-consuming manual processes used to check goods documents and pay customs and the small number of employees employed in the activities of "checking the goods documents" and "paying the customs fees," an electronic declaration and customs clearance system application was proposed. This system has the potential to provide at least four benefits. First, the customs officer at the KAS security checkpoint, who has all the necessary goods information, only needs to check whether it corresponds to the information in the goods documents submitted. Second, customs officers have sufficient time to analyze the received data and decide on the appropriate action for a specific item before it arrives at the checkpoint. Third, this application reduces the possibility of customs fraud. Finally, the time spent waiting by drivers for inspections and clearances at the document check and customs pay windows is reduced. The carrier's office can send advanced information via the internet to the customs agency's central database (the Israeli Government) or directly to the customs agency represented at the KAS security checkpoint.

4.4.2.3 Scenario 3: using portable detection and laboratory test equipment to scan the load on the truck. Instead of dogs and hand scanners in the "scan the truck" activity, this scenario proposes using portable detection and laboratory test equipment to scan the goods on the truck. This can reduce the processing time for this activity and make it easier to detect illegal items under truckloads. As well as lowering the probability of trucks being rerouted to the X-ray machine, which is executed by the "selecting the dubious truck" activity, that reduces overall waste time for the security checking and processing time of the goods.

4.4.2.4 Scenario 4: increasing the working hours in the cell area. Trucks carrying goods arriving from Israel are unloaded in the area of the cells after passing through a pre-checking process and then loaded onto vehicles operating inside the crossing to transport them to the Palestinian side of the Gaza Strip. The area of the cells is open only from 6:00 A.M. to 3:00 P.M. and does not receive trucks after this time. Thus, delayed trucks must wait until the next day to cross the KAS security checkpoint because of the limited capacity of this area in terms of time and number of workers, which significantly increases the waiting time for these trucks. The working hours in this area were extended to 8:00 P.M. to handle the greatest number of trucks.

4.4.2.5 Scenario 5: increasing the number of workers in the cell area without changing the number of shifts. This scenario is ongoing in the area of the cells and proposes increasing the number of workers in this area to 20 while adhering to the area's official working hours. Currently, approximately 14 workers work in this area to unload goods from trucks arriving from the Israeli side, sort them on the floor of this area and then reload these goods onto vehicles operating inside the crossing to transport them to the Palestinian side of the Gaza Strip.

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4.4.2.6 Scenario 6: combining all of the previous scenarios into a single model. This scenario assesses the overall impact of combining all previous scenarios into a single model. In other words, the current model of the process at the KAS security checkpoint is redesigned based on these scenarios to form a new model for the security checking process at this checkpoint.

4.5 TO-BE simulation results analysis and clearing function estimation

This section discusses Phase 3, which develops the BPS model for the TO-BE process with numerous scenarios. The simulation results are used as input data to estimate the clearing function for each scenario. The estimation results and network data provided as input data were then used to run the decision-support tool CFDM, and the results were used to compare the performance of the best TO-BE model with the AS-IS model based on the key performance indicators.

4.5.1 TO-BE simulation results analysis

Using the BPMN language, we constructed TO-BE models for each scenario. The resource utilization results for each scenario are summarized in Table 10 along with the average security-checking process cycle time and average waiting time. The results of the AS IS model (baseline) were added to this table so that the results of the scenarios could be compared with the baseline. Table 10 presents the results in two parts. The first section describes the utilization of various resources. The second part shows the process cycle and waiting times. It is worth noting that Scenarios 1–5 reduce the process cycle and waiting times, but not as much as expected. Thus, applying each scenario individually could not produce widely differing results compared to the AS-IS model results. In contrast, when all of these scenarios are combined into one scenario (Scenario 6), as illustrated in Figure 10, that is, the work of complete reengineering of the process and the addition of IT systems in many tasks, the results of the process cycle time, waiting time and resource utilization show a significant change. In conclusion, Scenario 6 considers the complementary role of all parts in the security checkpoint and suggests using related IT applications to accelerate processes and achieve excellent results.

4.5.2 Clearing function estimation for the chosen scenarios

The clearing function for each scenario was estimated using the same procedures as those described in the AS-IS analysis section. We generated the average WIP versus average cycle time data from each scenario's simulation output. Both throughput and WIP are measured in hours and are represented as the *y*- and *x*-axes of our clearing functions, respectively. WIP and throughput statistics were gathered from a one-week simulation run in which we replicated the AS-IS model's situation, with 400 trucks per day on average over five days at the security checkpoint ($9\,\text{h} \times 5\,\text{d} = 45\,\text{h}$). Consequently, for each scenario (400 trucks per day × five days), we obtained a [WIP, TH] data set with 2,000 data points. Figure 11 shows the workload in terms of the WIP versus throughput per working day for all scenarios (scatter points).

Equation (1) from Subsection 4.3.3 is used again to fit the data to the nonlinear function of the clearing function, as illustrated in Figure 10. Table 11 displays the estimated values of the capacity *C* and the CF curvature *C*' for each scenario.

The estimated CFs for each scenario were approximated using outer linearization with eight segments. The slopes α_l^k and intercepts β_l^k for each scenario are given in Table 11.

4.5.3 CFDM results for TO-BE model and KPIs

Table 12 displays the KPIs of the distribution model after applying the CFDM to each scenario for one working week (five working days). The first column represents the total cost of item distribution (commercial and humanitarian). The second column shows the average warehouse truck-loaded inventory per day, while the third, fourth, fifth and sixth columns show the average inventory at distribution centers, average WIP at security checkpoints (hours per day), average backorders (trucks per day) and average cycle times at security checkpoints (hours), respectively. The results of the baseline (AS-IS model) are included in the table for comparison with the various scenarios.

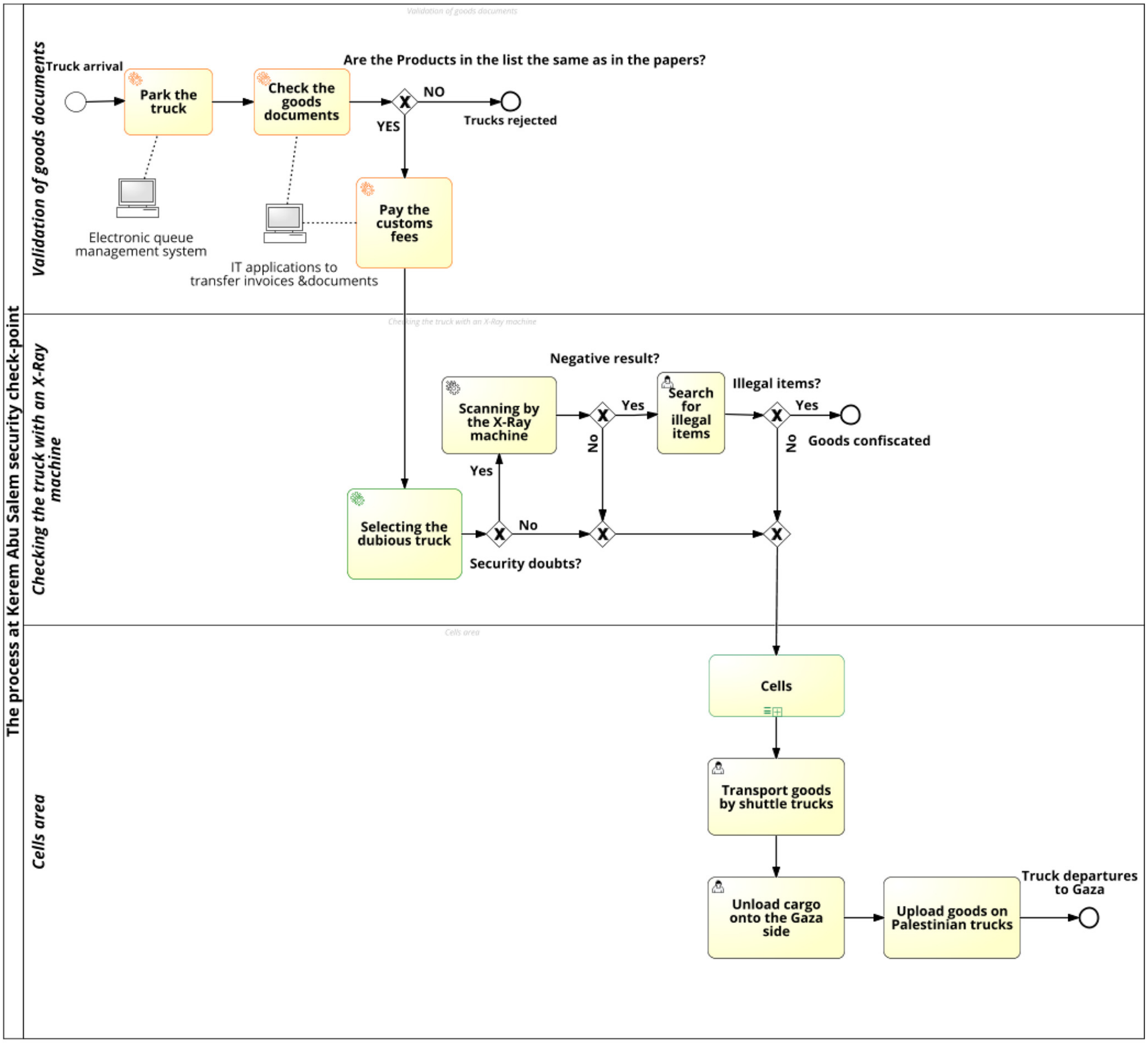
As shown in Table 13, using the BPR method to improve the process at the KAS security checkpoint improves the overall supply chain performance in terms of distribution costs and delivery lead-time. For example, when Scenario 6, which was chosen as the best scenario owing to the radical change it made in the inspection process at the KAS security checkpoint, was used, the relief-aid distribution costs were reduced by approximately 28%. In addition, the average cycle time at the security checkpoint was reduced by 90%, indicating that the reengineered process at the security checkpoint has a significant impact on supply chain performance and that any improvement in the process at the security checkpoint can positively reflect on relief-aid distribution planning performance. Scenario 6

Table 10 Performance measure for the selected scenarios

Performance measure	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Resource (utilization %)							
Cells area	87	80	98	93	46	50	50
Automated service	24	86	69	94	98	98	30
Validation of goods documents	74	36	36	75	58	58	6
Checking the truck with an X-ray machine	50	49	61	6	43	43	5
Gaza staging area	74	98	33	33	26	26	30
Time (hour)							
Process cycle time	3.05	2.30	2.26	1.79	2.27	2.40	0.77
Process waiting time	2.68	1.95	1.92	1.45	1.90	2.02	0.52

Source: Table created by authors

Figure 10 BPMN for the TO-BE model (Scenario 6)



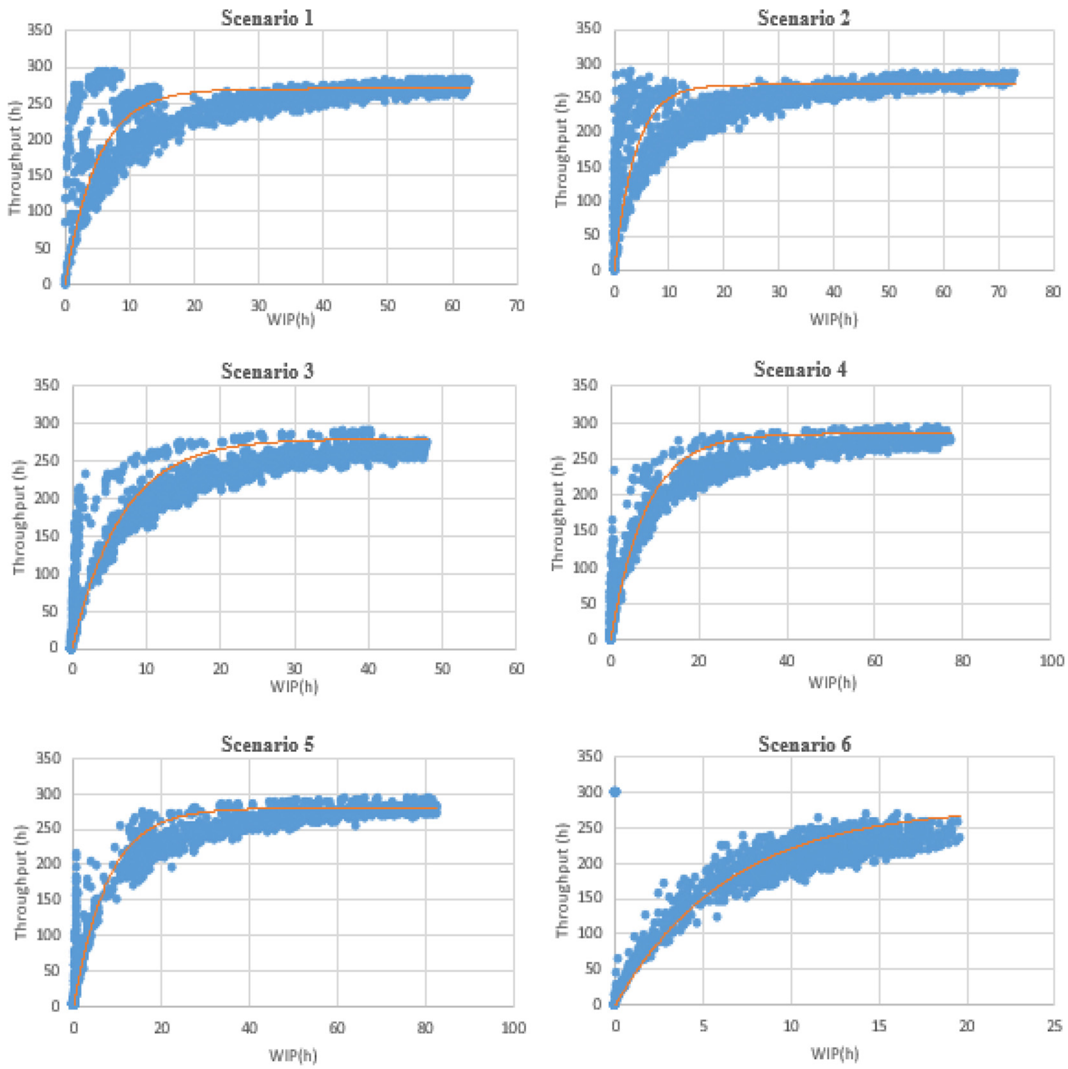
Source: Figure created by authors

attempts to overhaul most tasks at the KAS security checkpoint, implying that we must think radically and transformatively to redesign the current process at this checkpoint. As seen in Scenarios 3 and 4, the use of portable detection and laboratory test equipment to scan the load on the truck, as well as increased working hours in the cell area, can significantly reduce congestion at the KAS security checkpoint, potentially providing more solutions to the congestion problem and thus reducing the delivery lead-time and operation costs, such as average inventories and backorder costs.

4.6 Discussion and managerial insights

The experimental results show that the process at security checkpoints must be considered when developing a decision support tool for relief aid distribution plans in areas where security checkpoints play a vital role in controlling the flow of goods throughout supply networks. Owing to the procedures and limited capacity of security checkpoints, the current setup significantly hampers the effectiveness of commercial and humanitarian goods provisioning, which is one of the primary sources of delay in goods distribution to final destinations. In a humanitarian context, for example, the failure of relief organizations to address these issues at security checkpoints complicates relief efforts. Furthermore, humanitarian organizations only work with authorities to deal with crossing procedures, ignoring congestion and its effect on capacity at these checkpoints, which harms relief aid distribution in terms of costs and delivery lead-time. To this end, the goal of this

Figure 11 Estimation of CFs for the chosen scenarios



Source: Figure created by authors

Table 11 Estimated parameters of CF for the chosen scenarios

Scenarios	Capacity *C* (in hours/day)	CF curvature *C*'
Scenario 1	270	0.2
Scenario 2	270	0.26
Scenario 3	280	0.15
Scenario 4	280	0.109
Scenario 5	275	0.13
Scenario 6	270	0.155

Source: Table created by authors

study was to improve the decision support tool (CFDM) that generates efficient relief-aid shipment plans while accounting for load-dependent capacity constraints at security checkpoints by reengineering and simulating the current process at the security checkpoint using BPS. The output of the simulation was used to estimate the clearing functions incorporated in the decision-support tool CFDM, which was used to capture the nonlinear relationship between the WIP level and throughput at the security checkpoint to improve the efficiency of humanitarian operations in the entire supply chain.

As evidenced by the BPS results for both models, the TO-BE model outperformed the AS-IS model in terms of minimizing the process cycle and waiting times at the security checkpoint. Following this, once the estimations of the TO-BE clearing function are integrated into the CFDM decision-support tool, the tool exhibits superior performance in comparison to the utilization of the AS-IS clearing function estimation in relation to distribution costs and backordering, while also mitigating the lead time for the delivery of goods. The CFDM model includes congestion data in its clearing function constraints (capacity constraints in the CFDM model). As mentioned previously, congestion occurs as the number of trucks arriving at security checkpoints increases, necessitating an increase in WIP levels and resulting in delays and longer delivery lead times. This information is incorporated into the CFDM, which is used to plan the distribution of goods in both commercial and

Table 12 Piecewise linear approximation of CFs for the scenarios

Seg.	Scenario 1 α	Scenario 1 β	Scenario 2 α	Scenario 2 β	Scenario 3 α	Scenario 3 β	Scenario 4 α	Scenario 4 β	Scenario 5 α	Scenario 5 β	Scenario 6 α	Scenario 6 β
1	36.6	11.017	63.1	1.7	35.6	1.3	30.8	0.8	31.3	0.94	36.9	0.4
2	13.63	104.12	37.1	41.3	22.7	35	19.8	33	16.3	56.6	23.5	34.81
3	4.2	194.3	19.4	104.8	15.2	74	12.96	76	6.2	147	15.4	76.9
4	0.99	244.5	9.8	162.7	7.4	143.4	7.1	134.7	2.65	205	10.6	115
5	0.29	260.9	3.28	220.3	3.3	202	3.6	190	0.67	253.6	6.97	152
6	0.02	269	0.62	256.9	0.98	248	1.5	233	0.199	270	4.3	187.5
7	0.0014	271	0.001	269.9	0.05	277	0.4	266	0.053	276.95	3.02	208.45
8	0	270	0	270	0	280	0.007	280	0.0039	275	2.23	270

Source: Table created by authors

Table 13 Performance measures for the chosen scenarios of the CFDM model for one working week

Scenarios	Total cost ($)	Average inventory at warehouses (truckload)	Average inventory at distribution centers (truckload)	Average WIP at security checkpoints (hour per day)	Average backorder (truck per day)	Average cycle time at a security checkpoint (hour)
Baseline	$2,544,365	17	17	208	2.8	2.6
Scenario 1	$2,096,186	21	12	170	2.6	1.9
Scenario 2	$2,650,269	21.6	1.11	207	3.1	2.2
Scenario 3	$919,536	11.36	0	40.4	0	0.27
Scenario 4	$957,532	12.8	0	41.6	0	0.28
Scenario 5	$1,325,200	17	13.4	72.8	2.15	1.34
Scenario 6	$722,661	11.36	0	37.6	0	0.15

Source: Table created by authors

humanitarian contexts. After incorporating the TO-BE clearing function into this support tool, the proposed decision-support tool provided smoother shipment plans and accurately represented the goods distribution system.

4.6.1 Theoretical implications

Managers use decision support tools to help them make better decisions (Guner *et al.*, 2016). As disaster situations are unpredictable and challenging for managers to assess, decision-support tools are crucial in the context of humanitarian logistics (Rodríguez-Espíndola *et al.*, 2020). Consequently, decision support systems can help decision-makers solve problems, especially when faced with uncertainty, by enabling them to make quicker, more agile, and cost-effective decisions (De Boeck *et al.*, 2023). Our study contributes to the theory of humanitarian logistics by creating a decision support tool (CFDM) that helps planners and policymakers create effective plans for the distribution of relief aid while considering congestion at security checkpoints. However, little research has been conducted on how planning for the distribution of humanitarian aid is affected by traffic at security checkpoints.

We used business process redesign at the security checkpoint by implementing a BPR method. The hybrid simulation-optimization method is used to first simulate the AS-IS and TO-BE models at the security checkpoint and then use the simulation outputs to calculate the clearing function, which is then combined with the optimization model CFDM to achieve the best performance in the relief-aid distribution. The basic concept of a clearing function is found at the intersection of the queuing and mathematical programming models of production systems, where the functional relationship between the WIP and throughput is primarily determined by the variability of the arrival and departure processes (Missbauer and Uzsoy, 2020). The main reason for using the clearing function concept in our study is to represent a workload at a security checkpoint and have the ability to embed it in an optimization model to plan the distribution of goods over the next several periods and to ensure that the workload at a security checkpoint is at the correct level to achieve the desired throughput without excessively increasing the WIP and cycle time. Furthermore, using a business process redesign at the security checkpoint helps to improve the security checkpoint's capacity and process more goods that need to cross the security checkpoint in less time. In addition, to further mitigate the impact of congestion on the distribution planning of relief aid, the BPS output was used as an input parameter to estimate the clearing function, which is a novel clearing function concept. Finally, a real-world case study is used to validate the proposed decision support tool and BPS results. We filled the gap between theory and practice. The proposed decision-support tool has the potential to improve relief aid distribution planning, which will persuade more practitioners to use similar tools despite several limitations that require further investigation.

4.6.2 Practical implications

Practitioners can easily deal with crowded relief aid distribution at security checkpoints during the response stage using the CFDM and solution method as a decision-support tool. Practically speaking, the CFDM based on the TO-BE model performs better than that based on the AS-IS model, producing realistic and robust plans with improved on-time delivery performance, lower WIP at security checkpoints and almost no backorders at relief distribution centers. In addition, the CFDM based on the TO-BE model reduces the effects of security checkpoint congestion on delivery lead times and WIP, as well as the security process time at the security checkpoint, to account for potential demand peaks and to avoid a waiting time at the checkpoint and relief-aid backorders at relief distribution centers. Furthermore, the CFDM eliminates activities that cause delays in the security checkpoint inspection process based on the TO-BE model. Consequently, the implementation of CFDM, which is built on the TO-BE model, yields enhanced shipping plans and reduces delivery lead times.

We used a variety of scenarios to determine the best scenario for the process design. Technology must be used in the security process to speed up processing times and increase capacity at security checkpoints, which will increase the number of trucks that must pass these checkpoints, and make it simpler to find any illegal items loaded on these trucks. Finally, managers of relief operations will be able to supply the data for the CFDM model parameters needed to create a schedule for distributing aid, along with the quantities that must be sent to the distribution points for aid. The schedule can be rebuilt as the conditions and parameter data change. The model enables the generation of these solutions in real time, which aids in preventing congestion at security checkpoints that have previously hampered humanitarian operations in the distribution of relief aid.

5. Conclusions and future work

Authorities have established security checkpoints to control the flow of people in and out of the country. Congestion is caused by complex security procedures and increased flow through these security checkpoints, which delay the distribution of goods and increase the total cost of humanitarian and commercial operations. This study aims to improve the proposed decision-support tool for relief-aid distribution planning by re-engineering the security checkpoint process to reduce processing times for humanitarian items, reduce congestion at checkpoint entrance gates and then integrate the re-engineering efforts into the proposed decision-support tool, which is a continuation of our project to develop a decision-support tool for humanitarian organizations involved in humanitarian aid distribution planning.

This is based on the BPR principles proposed by (Hammer and Champy, 1993). A BPR method was used in this study to redesign the process at the security checkpoint. This study looks at six different potential scenarios for the reengineering process. These scenarios were created in collaboration with humanitarian organizations, Palestinian logistics service providers and the Palestinian Authority. Finally, the results of reengineering the process at the KAS security checkpoint show that the TO-BE model (Scenario 6) outperforms the AS-IS model in terms of processing cycle and waiting times. This can be achieved by balancing the workload across all sections of this checkpoint, using IT applications, and increasing the capacity of the checkpoint by extending open hours and hiring more workers, particularly in the cell area. Consequently, there is less congestion at the checkpoint gates.

A BPS technique was used to simulate both the current and reengineered processes to calculate the clearing function using the simulation output for both the current and reengineered processes. Subsequently, the results of the clearing function calculations were incorporated into a decision support tool (CFDM). KPIs, such as distribution costs, backordering and process cycle time, were used to compare the results of the CFDM tool when the clearing function calculation outputs of both the AS-IS and TO-BE models were used. The comparison results showed that the CFDM tool outperformed the others when the output of the TO-BE clearing function was used.

The proposed decision support tool assumes deterministic demand for relief items. Incorporating demand uncertainty into the model would undoubtedly improve the service levels at demand points. Managing demand uncertainty, however, would necessitate more traffic through security checkpoints, thereby increasing utilization. Furthermore, supply uncertainty is possible, particularly in humanitarian logistics. Therefore, strategically placing safety stocks at various points along the supply chain may reduce the workload at security checkpoints. A promising research area is the development of safety stock placement models in the context of humanitarian supply chains (Kovács and Falagara Sigala, 2021).

Note

1 https://bimp.cs.ut.ee/simulator/

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Appendix

Table A1 A table presenting the CFDM model's related data

Path/relief-aid				Relief-aid ($)
Transportation costs				
Nablus to Ephraim				121
Ramallah to Betuina				99
Hebron to Terqumia				114
Ramallah to Ephriam				186
Ramallah to Terqumia				223
Ephraim to Kerem Abu Salem				270
Betunia to Kerem Abu Salem				223
Terqumia to Kerem Abu Salem				143
Kerem Abu Salem to Rafah				107
Kerem Abu Salem to Khan Yunis				127
Kerem Abu Salem to Gaza City				143
Waiting costs at the checkpoints				
Checkpoint/relief-aid				Relief-aid ($)
Ephraim				236
Betunia				236
Terqumia				236
Kerem Abu Salem				1,071
Holding cost ($ per truck)				
Storage place/holding cost per relief truck ($)				Relief-aid ($)
Ephraim				11
Betunia				11
Terqumia				11
Kerem Abu Salem				15
Backorders cost ($ per truck)				
Distribution centers				Relief-aid ($)
Rafah distribution center				10,000
Khan Yunis distribution center				10,000
Gaza city distribution center				10,000
		Demand (truck per day)		
	Rafah distribution center	Khan Yunis distribution center		Gaza city distribution center
(Relief truck per day)	*Truck*	*Truck*		*Truck*
Day 1	47	47		86
Day 2	105	99		102
Day 3	102	88		176
Day 4	99	85		80
Day 5	96	81		28
Number of commercial trucks that arrived to the checkpoint during one working week				
Day/checkpoint	*Ephraim (truck)*	*Betunia (truck)*	*Terqumia (truck)*	*Kerem Abu Salem (truck)*
Day 1	18	1	1	9
Day 2	24	38	38	29
Day 3	31	50	50	1
Day 4	29	47	47	8
Day 5	1	1	1	30

Source: Table created by authors

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