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PARCEL FLOW-SIMULATION TOOL OF PARSEC SYSTEM-OF-SYSTEMS' SCANNING TECHNOLOGY ARCHITECTURE

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Abstract

The rapid growth of e-commerce has led to an unprecedented increase in parcel volumes, posing significant challenges for secure and efficient cross-border parcel delivery. This paper presents a preliminary study on the development of the PARSEC flow-simulation tool, which aims to improve parcel flow management for customs by integrating advanced detection technologies into parcel handling processes. The simulation model incorporates three scanning technologies into a system-of-systems approach. Initial results demonstrate the potential for high detection rates and reduced false alarms, thereby minimizing costly and time-consuming manual inspections. By addressing important issues in parcel management flows, this tool could significantly enhance decision-making for secure and efficient parcel processing, making it adaptable to different facility sizes and operational conditions.

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Key Words: Parcel Flow, Simulation Tool, Scanning Technology, Safety and Security, Customs, Performance Analysis

1. INTRODUCTION

The rapid expansion of e-commerce has significantly transformed global trade, leading to an unprecedented increase in the volume of parcels being shipped worldwide. This surge has introduced complex logistical challenges, particularly in managing the efficient and secure flow of international parcels. As e-commerce continues to grow, so does the necessity for advanced systems to handle the influx of packages in a manner that ensures both safety and compliance with international regulations.

A critical concern in parcel management is the dual issue of security and customs compliance. Outgoing parcel flows, especially those transported via air, must adhere to stringent security and safety protocols to prevent the carriage of hazardous or prohibited items onboard aircraft. Similarly, incoming parcel flows face rigorous customs scrutiny to intercept illicit goods, such as drugs and counterfeit products that attempt to enter the country. The need for robust scanning technologies is thus paramount in addressing these challenges, ensuring that parcels are processed efficiently while maintaining high security and safety levels as well as a high degree of regulatory compliance. Potential users of a parcel simulation tool in practice include Postal Operators, Customs and Border Protection Agencies, and international shipping, courier services, and transportation companies managing operations at their terminals.

Increasing the detection rate (hit rate) inevitably increases the false alarm rate, which consequently raises the time and effort needed to open and physically inspect the parcels. Limiting this work, on the other hand, hampers the system's ability to check all potentially illegal parcels thoroughly. Moreover, the high incoming flow (throughput) of imported parcels often exceeds the scanning capacities of current systems customs operate. To complement scanning, border control agencies regularly conduct risk assessments on cross-border parcels using information from declarations and other sources. This allows them to focus their limited inspection resources on the highest-risk segments of international parcel traffic.

Previous work in the field has explored various methods to enhance the detection capabilities of scanning systems. Traditional X-ray scanners, while effective to an extent, often fall short in detecting sophisticated concealment methods employed by smugglers. Recent advancements have introduced more sophisticated technologies and artificial intelligence (AI) based image analysis, which offer improved accuracy and efficiency. However, integrating these technologies into a cohesive system that can handle the high throughput of parcel traffic remains a significant challenge.

While there are numerous papers on discrete event simulation (DES) models of logistics / distribution centres and parcel flows of delivery systems, as well as works focusing on classification systems with hit rates and false alarm rates according to Receiver Operating Characteristic (ROC) curves, there is a noticeable scarcity of literature specifically addressing the simulation of parcel flows with integrated scanning technologies. The existing research often deals with indirect topics, but comprehensive studies dedicated to simulating parcel flows within the context of advanced scanning technologies are very rare.

In this context, the ongoing Horizon Europe project PARSEC is developing a new system-of-systems composed of three stages of non-intrusive inspection technologies: multi-energy photon counting detector, X-ray diffraction screening, and CTiX computerized tomography X-ray. This innovative approach aims to significantly enhance the detection capabilities of parcel scanning systems by combining the strengths of these advanced technologies into a comprehensive and integrated solution.

This paper presents a developed simulation model of a proposed scanning architecture designed to optimize parcel flow management. The proposed system integrates three advanced scanning technologies to form a comprehensive scanning solution. By leveraging the strengths of each technology, the model aims to enhance detection capabilities while maintaining a high processing speed to accommodate the increasing parcel volumes. The concept of the model is based on a scenario provided by the experts in customs, reflecting the desired system's architecture with deep experience and knowledge.

The primary contributions of this paper are as follows:

1. The development of a simulation model that demonstrates the efficacy of the proposed scanning architecture in a high-volume parcel processing environment.
2. An evaluation of the simulation results, highlighting the possible improvements in detection rates and false alarm rates in relation to different input parameters (*ROC* values) of the three machines, while also providing some insights into queues, waiting times, and utilizations of the machines.

The structure of the paper is organized as follows: The next section explores the dynamics of parcel traffic and related issues, providing an overview of the current landscape. Following this, we briefly present the PARSEC project and its proposed architecture, which integrates three distinct scanning techniques into a unified system. The subsequent section focuses on the simulation model, describing its development and analysis. Finally, we present the results and discuss their implications for future parcel management systems.

2. PARCEL FLOWS – STATE OF THE ART, TRENDS AND ISSUES

2.1 Growth of e-commerce and parcel flows

In this paper, the World Customs Organisation's (WCO) definition of e-commerce is used, which includes four key elements: online ordering, sale, communication, and payment; cross-border transactions and shipments; transport of physical goods; and delivery to a consumer, encompassing both business-to-consumer (B2C) and consumer-to-consumer (C2C) interactions [1].

Cross-border e-commerce has been growing rapidly in recent years, although this growth has slowed somewhat due to the recent economic downturn in China. The global cross-border B2C e-commerce market was valued at USD 719 billion in 2021 and is projected to expand at a compound annual growth rate of 25.8 % from 2022 to 2030 [2]. In fact, cross-border e-commerce sales are expected to grow twice as fast as overall global e-commerce sales in the coming years [3]. This growth in e-commerce value is the main driver of the increase in cross-border parcel volume.

While pre-pandemic growth hovered around 12-14 % annually [4], the pandemic-induced surge in online shopping led to a remarkable 36.7 % increase in 2020 [5]. This growth is attributed to several factors, including a rise in global internet penetration, a shift towards online shopping habits, and the proliferation of mobile technology and reliable delivery services [6]. E-commerce cross-border orders are estimated at 9.3 billion in 2020, 60 % of which appear intercontinental. Here is a breakdown of the 4.2 billion that involve Europe (including Russia and Turkey), based on McKinsey analysis: 1.7 billion intercontinental inbounds to Europe, 0.9 billion intercontinental outbounds, half of which are shipped from Europe to Asia, and 0.8 billion are intra-regional flows within Europe [7]. The corresponding inbound-outbound share of international parcels flowing through European borders is difficult to infer, based on e-commerce orders estimates, because statistics on imports/exports data cannot provide a consolidated view net of duplicating flows and because not all e-commerce orders are necessarily associated with parcel flows and vice-versa. However, by applying McKinsey ratios to the EU-27 international parcel figure (121 million), we may get a rough approximation of European parcel flows that may have occurred in 2020: 72 million intra-continental inbound, 24 million intra-continental outbound, and 24 million intra-regional figures.

2.2 Safety/security/customs issues

Many stakeholders play a role in ensuring the security, safety, and compliance of cross-border parcel traffic. Parcel operators – postal services and express courier companies – prioritize overall security and reliability, aiming to protect their services from illegal activities. These operators are legally responsible for organizing aviation security and safety screening for all air-bound parcels, although they often outsource this task to specialized security companies. Aviation security controls focus on detecting explosive and incendiary devices that could bring an aircraft down, while aviation safety controls target flammable and other hazardous substances, such as fireworks and lithium batteries, which cannot be transported by air.

In terms of law enforcement, customs officers are responsible for monitoring international parcels for illegal goods, security threats, and regulatory compliance. They also ensure the proper collection of duties and taxes on imported postal items. They target a wide range of goods, from narcotics and weapons to counterfeits and fiscal contraband – essentially any illegal item compact enough to fit inside a parcel. Police forces typically operate inland, but they are also interested in activities related to drug trafficking, large-scale tax evasion, and other serious crimes in relation to international parcel traffic.

Cross-border e-commerce presents unique challenges for parcel operators and law enforcement agencies due to the time-sensitive nature of the goods, the high volume of small packages, the large number of unknown receivers and senders, and the sheer variety of illegal goods that can be hidden in a parcel. Given the limited inspection resources and the significant impact of unchecked illegal activities in parcel traffic, new innovations are essential to address this issue effectively. New non-intrusive inspection technologies offer a promising solution: if integrated effectively into international parcel handling processes, they have the potential to detect a significant share of illegal parcel traffic cost-efficiently, without disrupting the flow of time-critical international parcel services.

3. PARSEC PROJECT – SYSTEM OF SCANNING TECHNOLOGIES

3.1 PARSEC project

The Horizon Europe project PARSEC, "Parcel and Letter Security for Postal and Express Courier Flows" (*https://www.parsec-project.eu/*, runs from October 2022 until September 2025), will deliver an ambitious set of solutions to fight the abuse of postal and express courier flows for criminal and terrorist purposes by developing, configuring, customising, and piloting innovative tools, services and security management approaches. The four PARSEC innovation areas and three use cases strengthen risk analysis and redefine threat detection and resilience capabilities of parcel service providers, customs authorities, police agencies, and other relevant stakeholders to fight crime and terrorism, put in place a stronger deterrent and to ensure safe and undisrupted postal and express services.

3.2 Multi-energy photon counting technology (DC/Varex)

Photon counting X-ray detectors directly convert X-ray photons into electrical charge. This allows both counting individual photon hits as well as classifying their energy in several bins. Image acquisition happens on the millisecond timescale with reduced image noise, enhanced contrast, and reduced susceptibility to artefacts. With a 100 % fill factor, photon counting technology is highly efficient and sensitive. This allows to maintain image quality whilst reducing the required radiation dose. With the ability to screen a wide range of goods, this versatility and adaptability make the technology useful for many customs applications.

One of the key advantages of photon counting technology is its ultra-high speed, which enables high system belt speeds of up to 2 m/s, facilitating real-time imaging and applications. This enables customs officers to make prompt decisions and isolate suspicious parcels for further checks.

3.3 X-ray diffraction platform (HALO)

The HALO X-ray diffraction platform utilizes X-ray diffraction-based materials discrimination, delivering highly accurate results within a 2-second timeframe and is an advanced technology, which provides increased detection capabilities and reduces false alarms.

With the current technology readiness level, the HALO platform has undergone rigorous development and testing, demonstrating high reliability in live environments, for example at parcel sorting centres and airports. Importantly, it is backward compatible with all major X-ray screening providers, ensuring seamless integration into existing systems.

3.4 Computerised Tomography x-ray (Smiths Detection)

X-ray Computerised Tomography is a non-destructive imaging technology that utilises X-ray beams to create 3D images by taking multiple X-rays from different angles of an object. By combining these slices, a three-dimensional (3D) model of the object can be created, providing valuable insights into its internal structure. The quality of the images produced by Computerised Tomography x-ray scanners is key to reducing the number of false positive, false negative rates and inconclusive results of the control procedures, which is an advantage over the use of X-ray systems.

4. PARSEC FLOW-SIMULATION TOOL

4.1 Parcel flow simulations

Speaking about flow simulation of parcel and letter operations, one might of course assume it is a well-known established process of modelling and analysing the movement of parcels, letters, and other items through a postal or distribution system, helping postal services and logistics companies to optimize their operations for efficiency, accuracy, and cost-effectiveness. As such, there are not plenty of new scientific papers published in literature, rather just a few mainly with presented case study analysis or specific technical issue related papers.

Parcel and letter flows could be simulated in a large scale, facilitating decision about transportation and sortation network (issues about centralized or non-centralized sortation, or number of sortation centres, like in [8]. On micro level, flow simulation of the parcels is related to the one facility, based on the layout problems and operation's bottlenecks, like in [9] or [10], specific technical issues, support for the decision-making [11] like analysis of the influence of manual data-entry to sorting machine efficiency and automation using ADC [12] or estimation of the potential impact of diverse parcel sizes and of uneven barcode quality on the productivity of bar code enabled sorting machines [13].

In all those cases simulation follows usual simulation modelling methodology, leading to the benefits:

- Optimized Resource Allocation: Simulation helps determine the optimal number of sorting machines, staffing levels, and transportation routes needed to handle varying volumes of parcels and letters efficiently.
- Reduced Costs: By identifying bottlenecks and inefficiencies, companies can cut down on unnecessary operational costs, such as labour and equipment usage.
- Improved Customer Service: A well-optimized postal system ensures timely delivery of items, leading to higher customer satisfaction.
- Quick Decision-Making: Simulation provides insights into the impact of potential changes without implementing them, enabling informed decision-making.

Additionally, there are numerous studies dedicated to classification systems, particularly utilizing Receiver Operating Characteristic (ROC) curves for performance evaluation (like in [14]). However, there appears to be a significant gap in the literature regarding the integration of detailed ROC analysis within the context of simulation flow models for parcel delivery. Developing this model aims to address this gap by incorporating comprehensive ROC analysis into the simulation flow, offering a novel approach to enhance the accuracy and efficiency of parcel detection systems.

4.2 Development phases and scenario of the PARSEC flow simulation tool

In PARSEC flow simulation tool, there is an additional aspect, based on how to facilitate integration of different detection technologies in a system-of systems. That is why PARSEC simulation flow tool is developing in phases, covering two distinctive parts.

The first part is a development of generic simulation models simulating flows disregarding actual physical constraints of one particular facility, focusing on the simulation of the detection processes regarding parcel and data flows. The focus is on the analysis of the simulation results regarding ranges of the detection probabilities in various stages of detections in a proposed architecture. In this way, users are able to gain insights into the potential (increased success rates of final detection) of adding the 2nd and 3rd stages of inspection, while at the same time decrease the false alarm rate and the amount of the unnecessary physical checks of falsely alarmed parcels. Based on test results of technologies (or at least assumptions in this time of the project's development), model is able to simulate various relations between increased possible detection rates and true and false positives, simulating processes and influence on increased number of false positives and unnecessary physical inspections in relations with the desired total successful detection. The second part of the flow simulation is a development of the model considering all important physical constraints and requirements in a selected real-life facility, therefore being a case study.

The mentioned scenario assumes a PARSEC system-of-systems with Risk Analysis (RA), which results in a portion of incoming parcels being directed to a proposed technology architecture set. This set consists of a high-speed line with a Varex scanning machine, a medium-speed line with HALO and subsequent Smiths Detection scanning machines, and finally, human inspection control. Additionally, this scenario incorporates a set of randomly selected parcels (random sample after risk analysis) to increase the utilization of scanning machines, implement continuous control of RA effectiveness, and improve the system's output results. Fig. 1 presents this scenario visually.

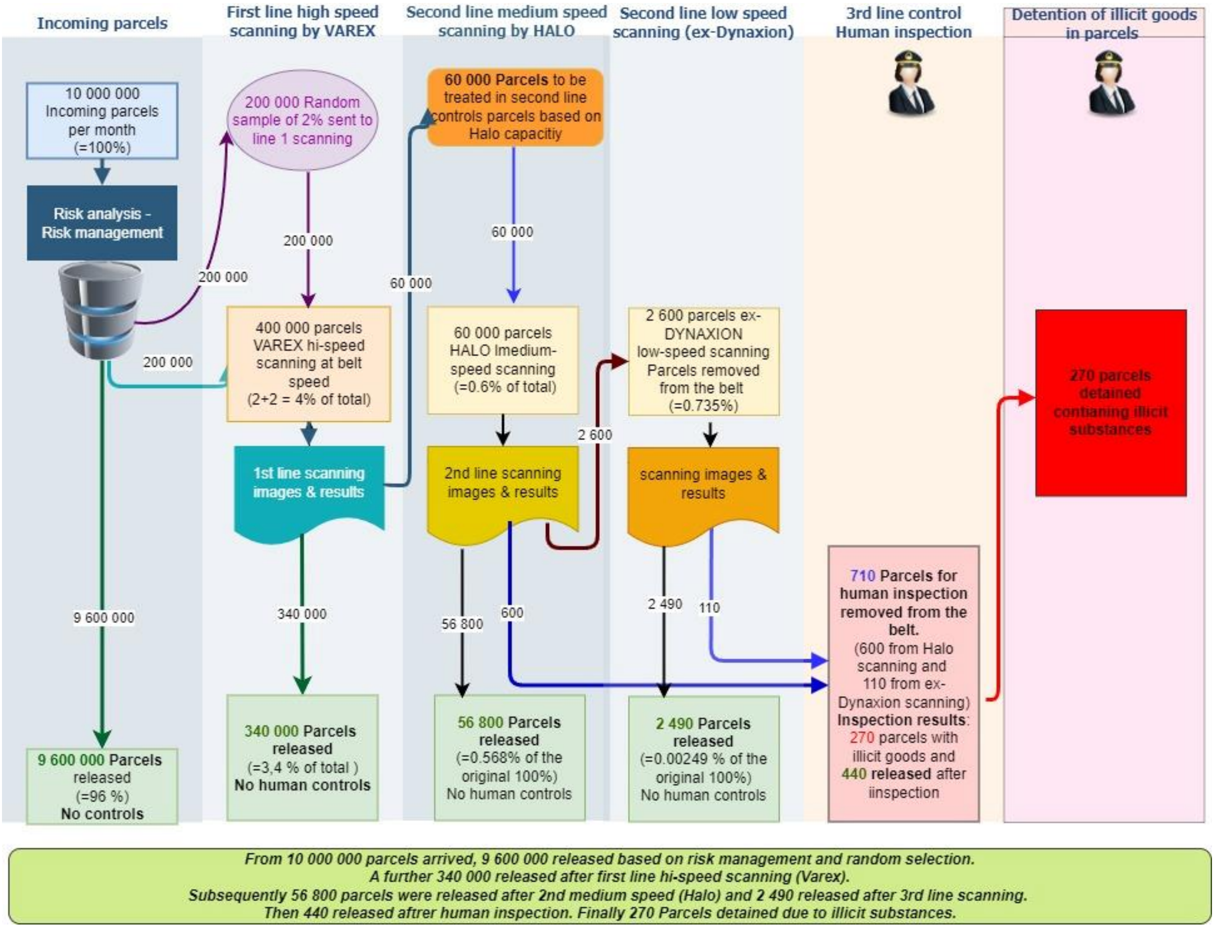

Figure 1: Scenario of PARSEC architecture's flow.

As shown in Fig. 1, this scenario assumes a large number of incoming parcels (10 million per month), similar to the volumes seen in the newest national parcel hubs. However, the generic simulation model is built only for the portion of the flow sent to the scanning system, in this case, 400,000 parcels. This implies that the model is adaptable for any size of parcel facility or operation, with the capability to scan all incoming parcels in smaller facilities based on total parcel throughput. This flexibility allows the model to define the total number of incoming parcels, parcels after risk analysis, or randomly selected parcels in a modified scenario.

4.3 Description of the model

The flow-simulation tool is modelled to follow the presented flow layout and the assumed amounts of parcels in certain parts of the total flow, as illustrated in Fig. 1. It considers the capacity of the detection equipment, the probabilities of parcels containing illicit goods in selected sets (based on experience or testing of RA), and the Receiver Operating Characteristics (ROC) of the machines (derived from tests conducted so far and anticipated assumptions). The splitting of the flow and amounts is based on the probability of illicit goods in scanned parcels and the ROCs of the machines, namely detection rate (hit rate) and false alarm rate of the Varex, HALO, and Smiths Detection scanning machines.

The ROC curves of machines for different types of illicit goods are not provided in this paper due to security reasons and ongoing tests and improvements based on machine learning. The scenario and current analysis are based on averaged values provided by one technology developer (project partner). The impact on the simulation results in this case is influenced by the selected *ROC* values for different thresholds, while in the future, these can be changed and will be updated with real values from the ROC curves of all three included technologies.

The model is created using Enterprise Dynamics 10.5, Discrete-Event Simulation (DES) software with pre-built objects, using object-oriented programming language to code the logic and behaviour of all permanent (arrivals, queues, conveyors, machines, etc.) and temporary entities (parcels). DES is one of the most important simulation techniques in decision-making in several areas [15].

Fig. 2 presents model's layout together with the results of a simulation run.

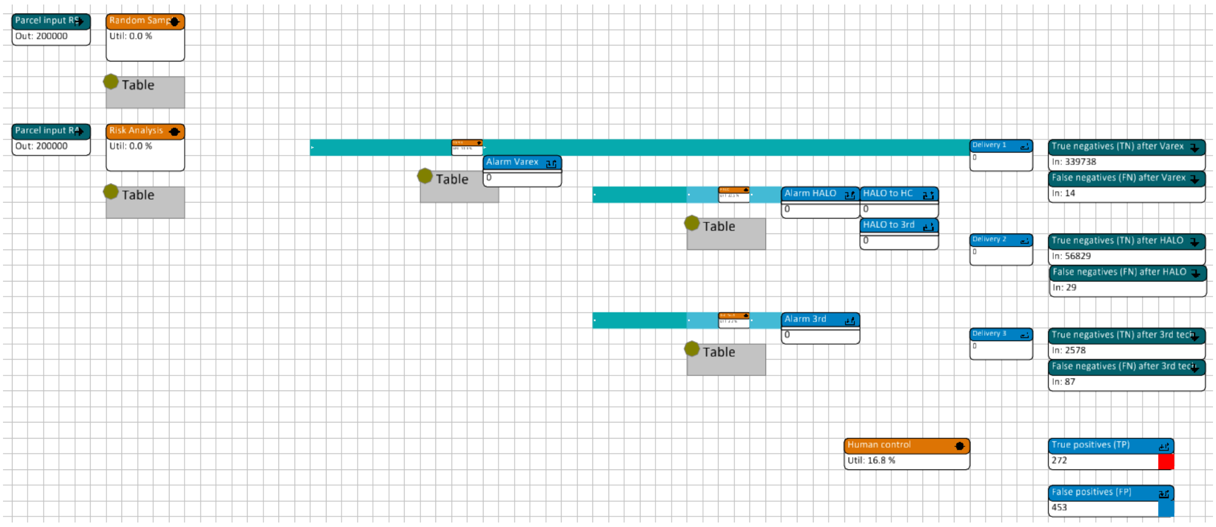

Figure 2: Flow-simulation model layout.

The model considers only incoming flows of parcels from Risk Analysis (RA) and random samples (RS), generating flow according to the average incoming throughput of 200,000 parcels of each type. Parcels are generated as positive (with illicit goods) or negative, based on given probabilities. In this preliminary version of the model, an aggregated probability for all illicit goods is used, without detailed results from the ongoing improved risk analysis methodology within the PARSEC project. Generated parcels create an incoming flow on the main conveyor system, representing the main belt line in larger parcel terminals, or a simple physical transfer of parcels in trolleys, loading onto the feeder of the Varex machine. Of course, this smaller number of parcels sent to the scanning systems follows the recent problems of scarce resources (in this case scanning devices and personnel), therefore the importance of well-structured systems as pointed in [16].

Based on the Varex's *ROC* values (detection rate and false alarm rate from the ROC curve for a selected threshold), four different types of parcels are sent out on two flows: True negatives (TN) and false negatives (FN) released on the main conveyor for delivery, and true positives (TP) and false positives (FP) diverted to the next stage of detection, the HALO machine. Routing and code for split decision are illustrated in Fig. 3.

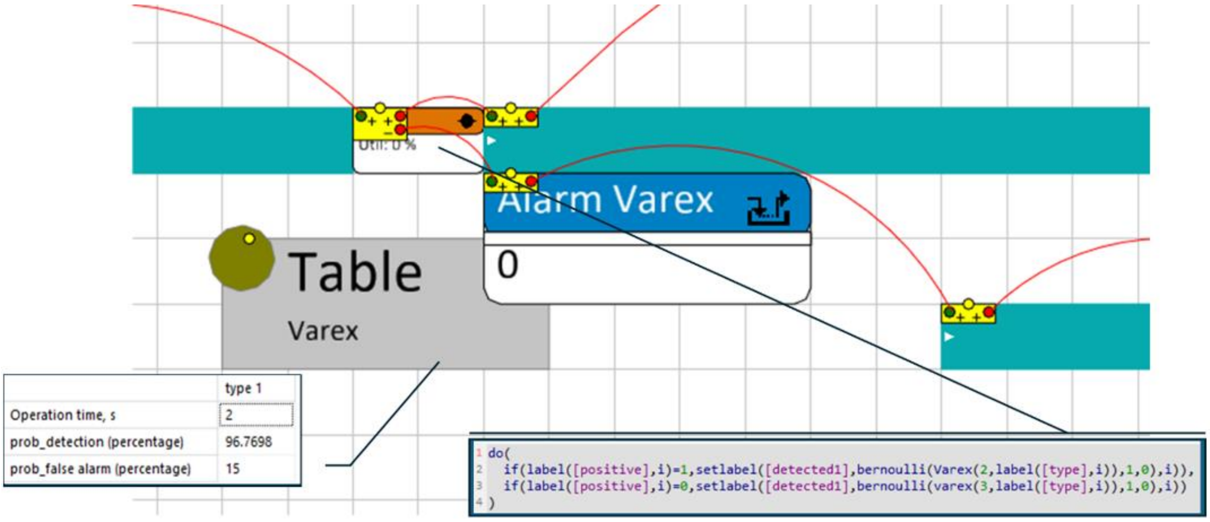

Figure 3: Parcel flow routing and associated code – example for the 1st detection stage.

The process is repeated on the HALO machine, but in this case based on two thresholds of the ROC curve. According to the initial scenario, a portion of the alarmed parcels (approximately 23 %) is detected as a "certain threat" and sent directly to the human inspection station, while the rest is diverted to the third detection machine. Routing and code for this part of the model are consequently more complicated, using two different thresholds of the ROC curve, resulting in the proposed outcome of the scenario. Routing of the parcels in this case has six different types of parcels on three flows: TN and FN released to delivery, while "certain" TP and FP are routed to human inspection and "uncertain" TP and FP to the Smiths Detection machine.

The third detection machine (Smiths Detection), again based on incoming parcel types, hit rate, and false alarm rate from the ROC curve selected threshold, releases TN and FN parcels to delivery while TP and FP are sent to human inspection.

Human inspection represents the physical opening and checking of alarmed parcels. In this case, a 100 % probability is assumed for detecting illicit goods (positive parcel) and for negatives (assuming subsequent repackaging and delivery, not simulated in this model).

The last part of the model on the right side represents objects to collect TN, FN, TP, and FP after release to delivery and human inspection, needed to get results of the simulation. In addition to this, there are also several "passing" queue objects with the function to control the number of parcels in all particular flows (also used for verification and validation of the model) and to analyse the appearance of possible queues and waiting times of parcels in different parts of the system.

The input parameters of the model are crucial for accurately simulating the flow and detection processes. These parameters include probabilities related to illicit goods, Receiver Operating Characteristic (ROC) values for the detection machines, and operation times for the scanning processes and human inspections. Detailed descriptions of these input parameters are as follows:

- Probability that a parcel after RA contains ilicit goods, P_{RA}: This parameter represents the likelihood that a parcel identified through Risk Analysis (RA) contains illicit goods.

- Probability that a parcel in RS contains ilicit goods, P_{RS}: This parameter represents the likelihood that a parcel from the Random Sample (RS) contains illicit goods.
- Averaged probability that a parcel sent to Varex contains ilicit goods, P_{RARS}: For the purpose of the initial analysis, this averaged probability is used, combining P_{RA} and P_{RS}. However, separated P_{RA} and P_{RS} values will be utilized in subsequent analyses.
- ROC values of Varex machine:
  - Probability of detection, Pd_{varex}: The likelihood that the Varex machine correctly identifies parcels containing illicit goods.
  - Probability of false alarm, Pfa_{varex}: The likelihood that the Varex machine incorrectly flags parcels as containing illicit goods when they do not.
- ROC values of HALO machine:
  - Probability of detection (threshold 1), Pd_{HALO}: The likelihood that the HALO machine correctly identifies parcels containing illicit goods at the first threshold (representing total detection).
  - Probability of false alarm (threshold 1), Pfa_{HALO}: The likelihood that the HALO machine incorrectly flags parcels as containing illicit goods at the first threshold (representing total false alarm).
  - Probability of detection for human inspection (treshold 2), $Pd\_{HALO\text{-}HI}$: The likelihood that the HALO machine correctly identifies parcels for human inspection at the second threshold.
  - Probability of flase alarm for human inspection (threshold 2), $Pfa\_{HALO\text{-}HI}$: The likelihood that the HALO machine incorrectly flags parcels for human inspection at the second threshold.
- ROC values of Smiths Detection machine:
  - Probability of detection, $Pd\_{new\text{-}tech}$: The likelihood that Smiths Detection machine correctly identifies parcels containing illicit goods.
  - Probability of false alarm, Pfa_{new_tech}: The likelihood that Smiths Detection machine incorrectly flags parcels as containing illicit goods when they do not.
- Operation times of scanning machines (scanning time) and human inspection:
  - Varex scanning time, T_{varex}: The time taken by the Varex machine to scan each parcel.
  - HALO scanning time, T_{HALO}: The time taken by the HALO machine to scan each parcel.
  - Smiths Detection scanning time, T_{new_tech}: The time taken by the Smiths Detection machine to scan each parcel.
  - Human inspection timetime, T_{HI}: The time taken for manual inspection of each parcel flagged for human inspection.

For the purpose of model development and validation based on the proposed scenario, and due to the ongoing process of testing to develop ROC curves for the three different scanning machines, *ROC* values for all three machines have been taken from the averaged values (curves) of the test results obtained so far for different types of illicit goods. It is important to note that the true values for specific types of illicit goods cannot be disclosed for security reasons. These averaged *ROC* values and curves are illustrated in Fig. 4.

This comprehensive set of input parameters ensures that the model reflects the performance and operational characteristics of the detection equipment and processes involved in the PARSEC system.

Pfa	*Pd*
0	0
0,01	0,628576027
0,02	0,819357246
0,03	0,897573131
0,04	0,921929872
0,05	0,933992499
0,06	0,941022204
0,07	0,946357015
0,08	0,950189896
0,09	0,95417257
0,1	0,957517842
0,11	0,960578119
0,12	0,963206244
0,13	0,964478488
0,14	0,966040804
0,15	0,967697993
0,16	0,969165946
0,17	0,970705674

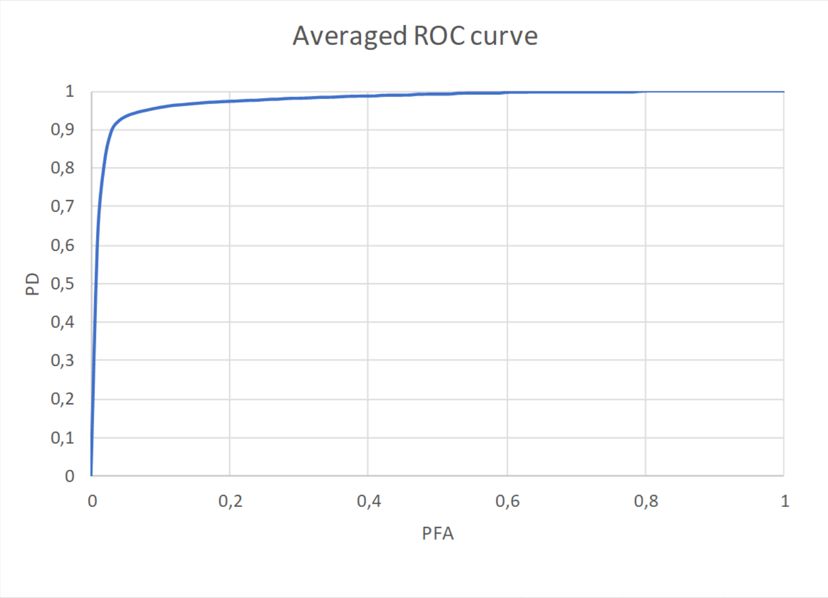

Figure 4: *ROC* values and curve used in a developed model for all three detection machines.

4.4 Evaluation of the results

During the model's development, verification was performed through a careful analysis of all parts of the model. Validation was conducted by calculating the expected number of True Positives (TP), False Positives (FP), True Negatives (TN), and False Negatives (FN) in different parts of the model. Utilization rates of the machines also verified the model, as they could be calculated based on the operation time and the number of parcels scanned.

The results of the simulation run with the selected input parameter values are presented in Fig. 2. These results demonstrate that the proposed scenario is achievable given the assumed probabilities of illicit goods in incoming parcels (based on expert assumptions and experience) and the selected *ROC* values (from initial tests of the scanning machines). The most important finding at this phase is the confirmation of the system-of-systems approach, which aims to achieve a high detection rate while significantly reducing the number of false alarms. This reduction minimizes unnecessary opening and checking of negative parcels, reduces manpower requirements in terminals, and decreases the delay time of parcels in the system before they proceed further in the delivery process.

The total hit rate of the system is 68 %, calculated from the simulation results in Fig. 2, based on the *TP* (found after human inspection) and *FN*s (*FN*1, *FN*2 and *FN*3) released after scanning by the three machines.

$$Hit\ rate = \frac{TP}{(FN1 + FN2 + FN3) + TP} = \frac{272}{(14 + 29 + 87) + 272} = 0{,}677 \qquad (1)$$

The total false alarm rate of the system is calculated analogously from the results in Fig. 2, based on the *FP* (found after human inspection) and *TN*s (*TN*1, *TN*2 and *TN*3) released after scanning by the three machines. With the majority of negative parcels released after three stages of scanning, the total false alarm rate is only around 0.1 %.

$$False\ alarm\ rate = \frac{FP}{(TN1 + TN2 + TN3) + FP} = \frac{453}{(339738 + 56829 + 2578) + 453} = 0{,}00113 \qquad (2)$$

The presented numbers for the two most important outcomes – the system's hit rate and false alarm rate – are highly illustrative when compared to those of a single scanning machine.

Using the ROC curve, for a hit rate of approximately 68 %, a single scanning machine would have about a 1.2 % false alarm rate. This higher false alarm rate would lead to the unnecessary opening of a large number of negative parcels (4795), resulting in more than ten times the required human hours. Conversely, using only one scanning machine and limiting the man-hours for physical opening and checks to match the results of the simulation would result in a significantly lower number of detected illicit parcels.

Evaluation of the utilization of the machines also revealed that, given the operation times and the number of parcels in flows diverted to machines based on the number of RA and RS and the thresholds of the machine ROCs, it is possible to modify the scenario. An increased number of parcels and/or adjusted thresholds with increased hit rates can be processed by the scanning machines. However, detailed simulation might reveal potential queues and congestion, leading to an increase in falsely alarmed parcels, which would require more man-hours and operators. Given that the detection machines are still undergoing testing, the final operational scanning times in relation to the conveyor belt speed will be further evaluated and updated.

5. CONCLUSION

This preliminary research outlines the development and potential of the PARSEC flow-simulation tool, aimed at enhancing the management and security of parcel flows amidst the rapid expansion of e-commerce. The proposed simulation model integrates three advanced scanning technologies into a conceptual system-of-systems designed to optimize parcel detection processes.

The initial results from the simulation suggest that the proposed system could achieve high detection rates while significantly reducing false alarm rates, thereby minimizing unnecessary manual inspections. Achieving this balance is crucial for maintaining both efficiency and security in high-volume parcel processing environments.

Key insights from the simulation indicate that a multi-stage detection process has the potential to enhance detection capabilities and reduce false alarms by strategically combining different technologies. This approach not only aims to improve the accuracy of detecting illicit goods but also to reduce the operational burden on human inspectors, leading to potential cost savings and improved service delivery times.

The validation and verification processes have confirmed the model's preliminary reliability, aligning simulated outcomes with expected real-world scenarios. Moreover, the model's flexibility allows for adjustments based on varying input parameters, making it adaptable to different facility sizes and operational conditions. As the development of the PARSEC flow-simulation tool progresses, future work will focus on refining the *ROC* values with more data from ongoing tests and adjusting the scenario regarding increased utilization of the machines.

In conclusion, while the PARSEC flow-simulation tool is still in development, it represents a promising concept for advancing parcel security and efficiency. By leveraging advanced scanning technologies and comprehensive simulation modelling, this tool could enhance decision-making for more secure and efficient parcel traffic.

In the further work, the model will be revised in accordance with the constantly emerging knowledge about the detection performance of the mentioned three technologies, as well as to account for the increased overall parcel throughput entering the detection system. Additionally, since this simulation model is based on statistical expectations, the development of an optimization model is planned to select the thresholds of the three technologies (*ROC* values) to either minimize false alarms or maximize the hit rate, constrained by the maximum possible throughput regarding the operational speed of the machines.

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