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Analysis of passenger and vehicle flows with microscopic simulations as a result of security checks at ferry terminals

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Abstract

The events of 9/11 in the United States led to a significant strengthening of security measures within air transport. The maritime sector could also be a target of terror attacks.
For this reason the International Convention for the Safety of Life at Sea (SOLAS) was adapted in the wake of the 9/11 attacks in order to increase security in the maritime sector. In particular chapter XI-2 was added to the SOLAS Convention on 12 December 2002 to face potential threats to ships and port facilities. Chapter XI-2 includes the International Ship and Port Facility Security Code (ISPS Code), which contains special measures to enhance maritime security.
These measures are risk-based and differ according to the security threat to ships or port facilities.
All measures of the different security levels (level 1-normal, level 2-heightened, level 3-exceptional) must be fixed by appropriate security plans and responsibilities must be assigned to security officers.
However, there are areas in the maritime sector in which the security still shows gaps. For example there are no security checks for passengers, vehicles and cargo at ferry shipping, in contrary to cruise shipping. Although it is mandatory to perform access controls, the inspection of passengers and vehicles according to dangerous objects is not required and therefore missing. For this reason ferry shipping is committed to a high risk of terror attacks.
The question arises of appropriate measures to increase security in the ferry shipping. At the same time it is important to investigate the consequences on the traffic flow that would be caused by additional security measures.
Therefore, we transferred the established security measures of the aviation sector to the ferry shipping. In the aviation sector a security check according to dangerous objects is applied to everyone and everything who and which wants to enter the secure area. In addition to the well-known security checks of passengers also security checks for employees and vehicles are carried out.

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People are scanned with metal detectors and, if necessary, followed up by a manual check, regardless of whether they are passengers, staff or visitors. Their luggage is scanned by X-rays. The bottom of vehicles is screened for bombs with mirrors. The security officer goes around the vehicle with a long pole to which a mirror is attached. The interior and the trunk of the vehicle are inspected by view control. If necessary, there can be made more detailed follow-up checks.
We transferred these security checks from the aviation sector to a ferry terminal by modeling them in a microscopic simulation. We examined the consequences on passenger and vehicle flows resulting from the implementation of such security measures. Our simulations deliver information about queue time and queue length at security checkpoints as well as the number of passengers, who will eventually miss their ferry boat as a consequence of these additional checks. Our analysis shows the serious consequences on the traffic flow which would result from an implementation of such security measures at ferry terminals.

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Keywords: security; security check; passenger flow; vehicle flow; microscopic simulation; ferry terminal

1. Introduction and the state-of-the-art

The maritime sector is at risk from a considerable number of criminally motivated threats. The nature of such threats varies widely, ranging from human, weapon and drug trafficking, to theft, to piracy and terrorism.

According to an OECD analysis from 2003, maritime transport is attractive to those criminals who pose a threat primarily due to the amount and variety of the goods transported by ship. [OECD (2003)] Over 90% of global trade takes place via sea routes. A large proportion of these goods are transported by means of 50,000 ships, which are operated internationally by around 150 different countries. [ICS (2015)] The development of goods flows by ship has increased continuously, except for a drop in 2009. Any interruption of these goods flows, and therefore also international trade, causes enormous costs and can also lead to serious supply bottlenecks.

Another risk factor mentioned by the OECD is the fact that the maritime sector is a complex, international transportation network. [OECD (2003)] It is very much prone to the prevailing threats and difficult to secure against them. Security is therefore a significant challenge. This is partly due to the technical challenges, such as rapid screening of vehicles and containers.

External factors can also cause difficulties, one example being in the ferry business. While passengers, luggage checks and on-board operations can be relatively well monitored for example on cruise ships, security measures on ferries have to be adapted to specific conditions. Loading and unloading ferries must happen quickly, for example. Most passengers also start their ferry journey spontaneously, which makes checks in advance impossible. [Jenisch (2010)] Cars and busses are also frequently transported and these are not easy to technically monitor, meaning that only spot checks are possible to keep processes running quick.

The maritime transport sector is particularly attractive to terrorists. This is due besides the reasons mentioned so far to the versatile usage of watercraft. They can be advantageous in terrorist acts either directly or indirectly, as they themselves can be deployed as a weapon, just as aircraft were in the attacks on the World Trade Center on 11th September 2001, or as a means of transporting weapons or other items which may be of benefit to terrorism. Taking hostages aboard ships and demanding ransoms is also a possibility.

Symbolic victories are also clearly of considerable importance to terrorists. The sinking of a single ship, be it military or commercial, or a harbour put out of service, can have a great influence on the population and gain terrorists the public attention they seek. [Simon, 1986] It must be mentioned at this point that passenger and cruise liners, similar to aircraft, are particularly sensitive symbolic targets. [Jenisch (2010)]

No security checks are currently carried out at Germany’s ferry terminals in contrast to cruise ship terminals. This is partly due to the lack of a legal requirement to do so. Access controls are mandatory, but there is no inspection of passengers or vehicles for dangerous items. So we introduced virtual checkpoints due to this security loophole in order to perform preliminary checks on their effect on traffic flows. Our research was then carried out on alternative processes and checkpoints for ferry terminals with the aid of the TOMICS microscopic simulation software developed at the DLR.

Nomenclature

AA Radius	Affected Area Radius
DLR	German Aerospace Center
ICS	International Chamber of Shipping
OECD	Organisation for Economic Co-operation and Development
PAX	Passenger
TOMICS	Traffic Oriented Microscopic Simulator

2. Concept and simulation

2.1. Concept for alternative checkpoints

One alternative to the current situation in Germany is to introduce checks at ferry terminals which go beyond the currently implemented access controls. One option is to apply the security checks which are considered sufficient for air transport to ferry transport.

In aviation, everyone and everything which has to enter the secure area of an airport has to pass through a security check. [Reg. (EC) No 2320/2002] Besides the commonly known security checks for passengers, checks are also carried out on staff and vehicles. People are scanned with metal detectors and manually searched where necessary, regardless of whether they are passengers, staff or visitors. Their luggage is also x-rayed. The bottoms of vehicles are searched for explosives using mirrors. The security officer goes around the vehicle with a mirror which is attached to a long rod. The vehicle's interior and boot are checked visually. More thorough checks may also be performed. When vehicles are inspected, the occupants have to be present so that they cannot later claim that something has disappeared or been damaged. [Deutschmann et al. (2011)]

We applied this concept to a well-known German ferry terminal to investigate its effect on traffic. The procedure applied to perform the checks at ferry terminals is shown in Figure 1. The on-site situation was taken into account when implementing the security checks. The layout of this particular ferry terminal allowed for a maximum of ten security check lines. The presence of the passengers during checks on their vehicles also resulted in idling times at the security check devices for people and luggage. In order to better utilise capacity, it makes sense to allocate one inspection line to each two lanes for people and for luggage. This does not only better utilise capacity – it also reduces costs, since expensive inspection devices do not have to be purchased for every lane. Savings in personnel costs are also a factor because, for example, if there are ten lanes, only five checkpoints for people and for luggage have to be provided instead of ten. In our concept groups of people arriving on coaches alight at the terminal and undergo security checks in the terminal. The bus driver queues his vehicle in a security check line and is dealt the same way as a truck.

2.2. Simulation model

The Traffic Oriented Microscopic Simulator (TOMICS) is a microscopic simulation program for modelling individual person movements in an airport terminal. It was designed as part of the "Management of Intermodal Airport Traffic" project and has been developed continuously since then.

TOMICS was designed to allow almost all traffic and clearance processes at an airport and beyond to be simulated. The basis for this is formed by events described within a pre-defined space between two points. All movements in the space are simulated with time-step-based calculations of direction and speed, taking into account a conflict check. The input parameters required for the simulation are stored in the TOMICS database following checks for completeness, plausibility and their suitability for use in fulfilling the task.

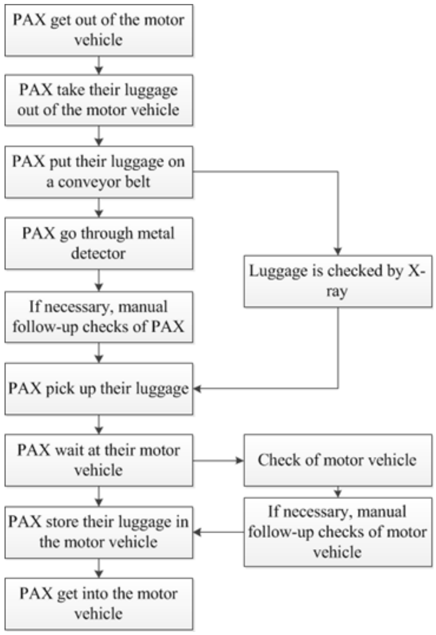

Fig. 1. Security check process.

In the 1970s, John Fruin transferred the level of service concept known from car transportation to pedestrian traffic flows. His assumption was that each person has their own desired speed which can be achieved depending on the nature and scope of hindrance by other people. The average speed maintained by people without any handicap is around 4.9 km/h. The people in TOMICS are allocated an individual walking speed ($v_{individual}$) on initialisation. If there are no hindrances, a person will move at the initialised desired speed. As the crowd of passengers becomes denser, the speed of movement decreases. The people in the simulation move at the speeds all derived from the same Fruin distribution. [Young 1999]

The minimum distance between two people is determined by entering the “Affected Area Radius” (AA Radius). When two or more people come closer to each other than the defined AA Radius, they begin to repel each other. The closer they come under this radius, the stronger the repelling forces become. This is similar to two magnets. When pedestrians obstruct each other, the AA Radius halves following an adjustable time interval until the people can pass each other by. This time interval is set at 3 seconds in this model – a value which has proven itself throughout numerous simulations performed at the Institute of Air Transport and Airport Research.

The simulation model we used in our approach was designed to be as realistic as possible. The simulation logic, specially developed for this simulation, enables the procedures required for the security process. This means that vehicles (busses, trucks and cars) initially distribute themselves evenly across ten lanes. The vehicles stop at the checkpoint and the occupants alight with their luggage. They then go to the passenger and luggage checks, where they are cleared in the same way as at an airport (see Figure 2). This means that the people have to remove any metallic items and take off their jackets or coats. These are put onto the conveyor belt with their luggage and are x-rayed. The passengers pass through a metal detector and then collect their personal belongings and luggage from the conveyor. Follow-up checks may be performed on passengers or luggage if required. The people then return to their vehicles.

When all the people are back at their vehicles, the vehicles undergo checks. A security officer inspects the bottom of the vehicle using a mirror. The interior and the boot are checked visually. A more thorough check may also be performed at this point. Once the vehicle check is complete, the people put their luggage back in the vehicle, get in and drive to the terminal grounds.

2.3 Data basis

The data used in the simulation model originate from different sources. The ferry timetable used in the simulation is very close to the real one used in the selected ferry terminal. The maximum capacity with regard to people and loading metre was ascertained from information provided by the ferry lines. This data serves as a basis for calculating the distribution of vehicles arriving at the terminal.

Some other assumptions were made in calculating the arrival distribution. One example is that the ratio of trucks to cars per loading metre is 50%. This means that half of the loading metres are taken up by trucks and half by cars. It is also assumed that each truck is occupied by one person. The number of passengers per car varies between one and three. The frequencies for this are evenly distributed in the simulation.

The vehicles arrive at the ferry terminal as has so far been the case at least half an hour before the ferry departs. A time range of three hours is assumed for the arrival of vehicles. Most ferry passengers arrive via roads and most drivers plan in some buffer time to account for possible traffic jams or diversions, so this time range is realistic for ferry transportation. A normal distribution is assumed for arrival distribution at each ferry.

The resulting arrival distribution for the vehicles is shown in Figure 3. It contains all vehicles for all ferries that departure at one day. Monday is taken here as the example of a travel day.

Three vehicle peaks are visible correlating to the departure timetable. These occur between 4am and 6am; 12noon and 2pm; and 8pm and 10pm. The arrival distribution for Tuesday and Wednesday is very similar. On Thursday and Friday, there is a small additional peak at 4pm and 6pm respectively. These peaks correlate with the timetables for the two days, where additional ferries depart.

75% capacity utilisation was also simulated in addition to 100% because it cannot always be assumed that the ferries are all full every day. Fluctuations can be seen as a result of the time of day for example. Both capacity utilisation scenarios were simulated for travel on the days Monday through Friday.

Security checks on the vehicles were documented in a measurement series as part of the Critical Parts project, which looked at security at airports with regard to supplies and personnel. These checks were carried out in accordance with §8 Luftsicherheitsgesetz [German Aviation Security Law]. The measurements were performed by the project partner FIS (Flug- und Industriesicherheit Service- und Beratungs-GmbH) [Flight and Industry Security

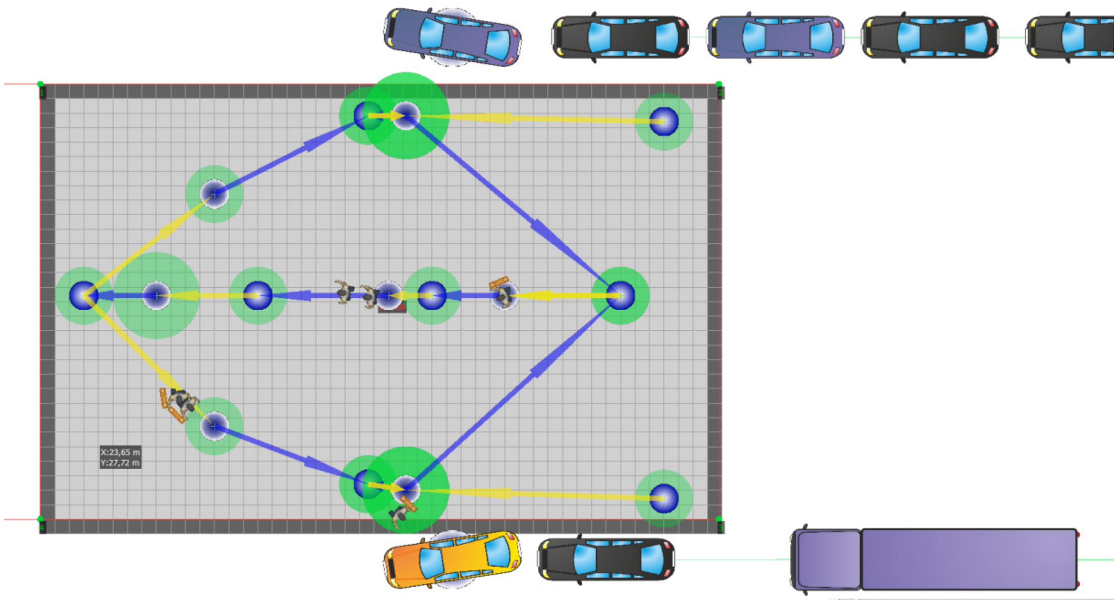

Fig. 2. Detailed depiction of a security check.

Services and Consultation] at Hamburg Airport. [Deutschmann et al. 2011] The following component processes of the security checks were measured:

- removing personal items
- passing through the metal detector incl. possible additional checks
- collecting personal items incl. possible additional luggage checks
- vehicle checks

The measurements were transferred into probability density distributions as part of the assessment and used in the simulation.

In order to add to the realism of the simulation, investigations were conducted into how long it actually takes in reality to get in and out of a five-door car with luggage. These trials were conducted by staff at the DLR's Institute of Air Transport and Airport Research. The number of passengers was varied between 1 and 3. The time was measured from the call from the security staff to alight from the vehicle, to taking the luggage out of the boot, through to all the vehicle occupants entering the passenger security check area. The time required to get back into the car included putting the luggage back into the boot, all the passengers getting into the car and ended once the car was ready to go.

Table 1 shows the average times for entering and exiting the vehicle in seconds. These figures are the result of around 100 measurements.

Table 1. Average entry and exit time.

	Ø time to enter [sec]	Ø exit time [sec]
1 person	21	19
2 persons	26	24
3 persons	28	24

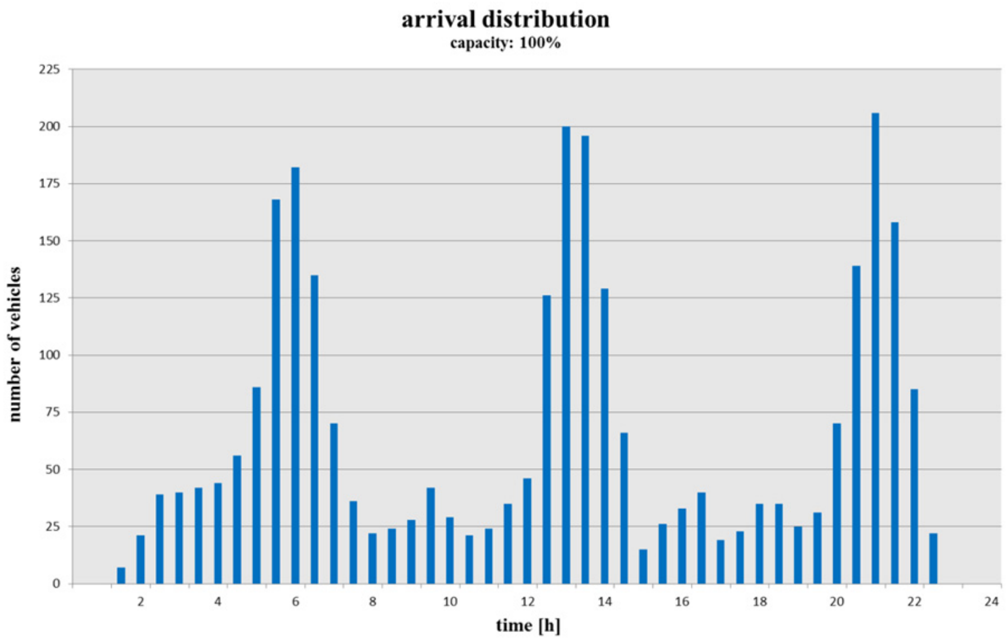

Fig. 3. Arrival distribution for vehicles at 100% capacity utilisation (Monday).

3. Results of the simulation

The simulation covered the travel days Monday to Friday and the described arrival distribution was applied. Two simulation runs were performed with the two different levels of capacity utilisation (100% and 75%). The resulting waiting times, the number of vehicles which could not reach their ferry on time due to the security checks, and the total processing time at the security checkpoints were all measured.

Figure 4 shows the waiting time for Monday when operating at 100% of capacity. When compared to the arrival distribution (see Figure 3) it becomes apparent that long waiting times occur following the peaks in the distribution.

After the peaks in the arrival distribution occur between 4am and 7am; 12noon and 2pm; and 8pm and 10pm, the waiting times at 8am, 3:30pm and 11:30pm are the longest. The waiting times rise in a linear fashion before each peak and fall abruptly afterwards. The abrupt fall results from many vehicles which did not reach their ferries leaving the queue. The maximum waiting time for all days at 100% of capacity ranges between 147 and 160 minutes and the average waiting ranges between 52 and 65 minutes (see Table 2).

Table 2. Maximum and average waiting times.

		Mon	Tues	Wed	Thurs	Fri
100% of capacity	Maximum [min]	147.45	155.29	152.28	160.29	157.21
	Average [min]	52.68	57.02	55.93	64.52	58.66
75% of capacity	Maximum [min]	131.90	131.66	131.82	128.26	144.24
	Average [min]	44.80	47.58	47.58	48.13	47.82

When closely examining the waiting time (see Table 2), it can be seen that Monday at 100% of capacity has a lower maximum and average waiting time, despite a greater number of vehicles than on Tuesday and Wednesday. This is due to the timetable. On Monday, in contrast to Tuesday and Wednesday, one additional ferry sails, which however does not cause any interference with the rest of the timetable. This means that the average is lower because there are a higher number of vehicles and fewer reciprocal effects. The longest waiting times are on Thursday and Friday. This is due to the greater number of vehicles and the overlap in the arrival distributions for the different ferries.

Figure 5 shows the waiting times for Monday at 75% of capacity. The waiting time pattern is very similar to that for 100% capacity utilisation. As expected, the maximum waiting time is lower (128 to 145 minutes) due to the smaller number of vehicles. The average waiting time is also shorter at 44 to 49 minutes.

An interesting point on all travel days with 75% capacity utilisation is the intervals between the peaks, with shorter waiting times compared to the intervals at 100% capacity utilisation. One explanation for this is the smaller number of vehicles combined with the maximum waiting time and the linear rise and abrupt fall in waiting time.

Table 3 shows the total number of vehicles generated in the simulation per travel day and per capacity utilisation case and the number of vehicles which did not make it to their ferries on time. The latter is also shown as a percentage of the total number of vehicles. As can be seen in Table 3, the Friday (followed by Thursday) is the day with the most traffic. The number of vehicles which did not make it to their ferries is between 36% and 39% when operating at 100% of capacity and 24% and 26% when operating at 75% of capacity. This proportion is very high and would not be acceptable in reality.

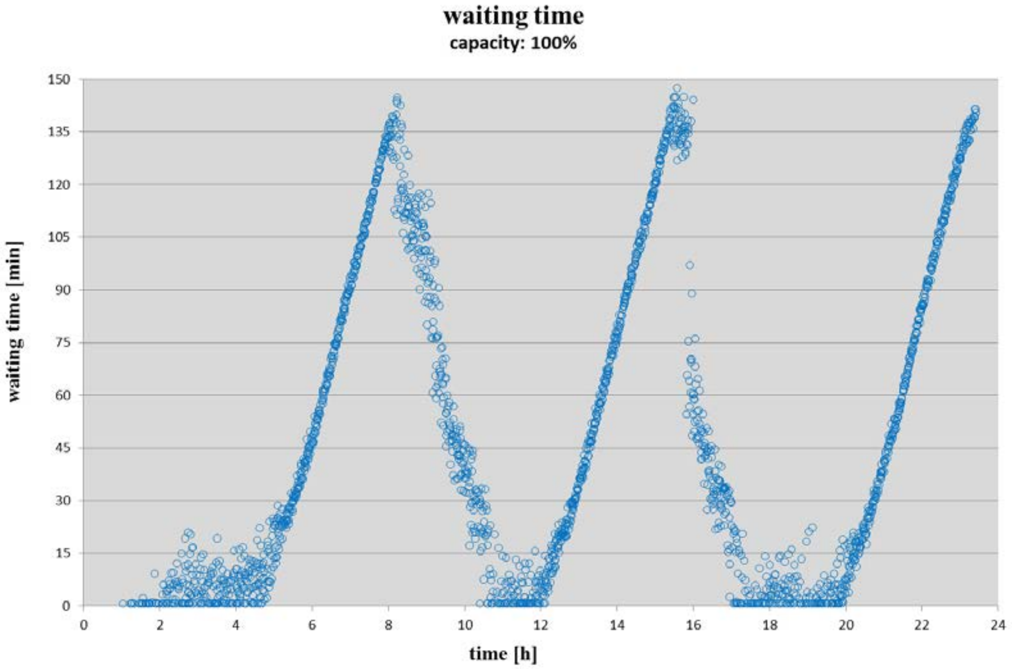

Fig. 4. Waiting times for vehicles when operating at 100% of capacity (Monday).

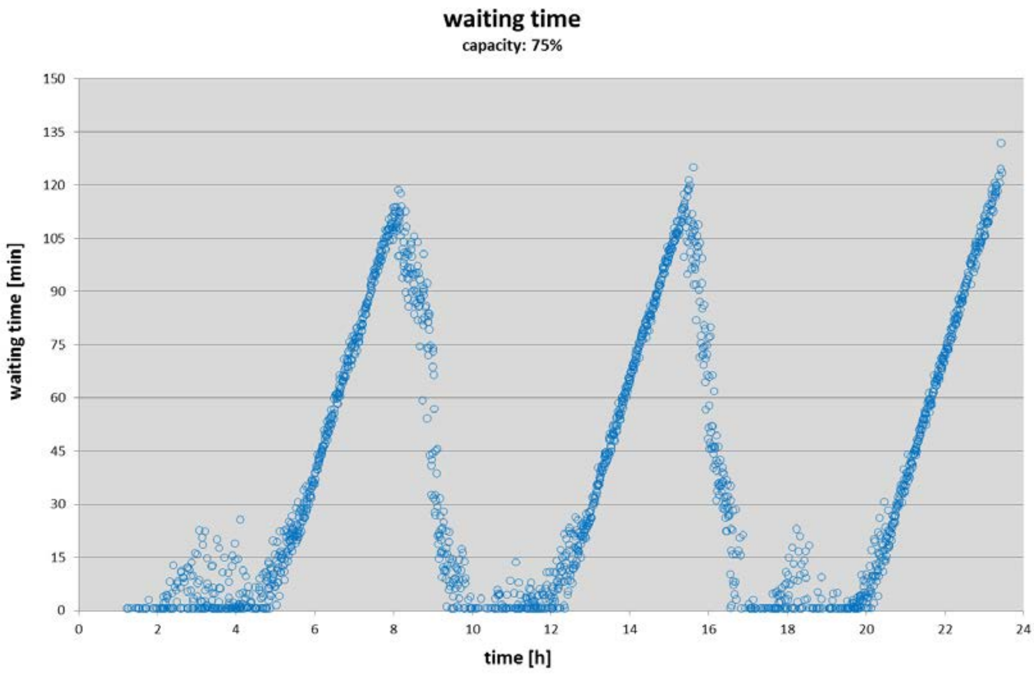

Fig. 5. Waiting times for vehicles when operating at 75% of capacity (Monday).

Table 3. Number of vehicles (total, ferry not reached).

		Mon	Tues	Wed	Thurs	Fri
100% of capacity	Total	2876	2748	2748	3003	3124
	Not reached	1038	1048	1019	1170	1223
	Proportion (%)	36	38	37	39	39
75% of capacity	Total	2143	2048	2047	2238	2328
	Not reached	505	508	521	539	612
	Proportion (%)	24	25	25	24	26

Figure 6 shows the processing time at the security checks. The measurements covered the total processing time from stopping the vehicle to the vehicle driving into the terminal. This included all the process steps shown in Figure 1 in the processing time.

Figure 6 provides the median (black line), the 25% and 75% quantiles (blue squares) and the maximum and minimum processing time for the vehicle occupants (1–3 people).

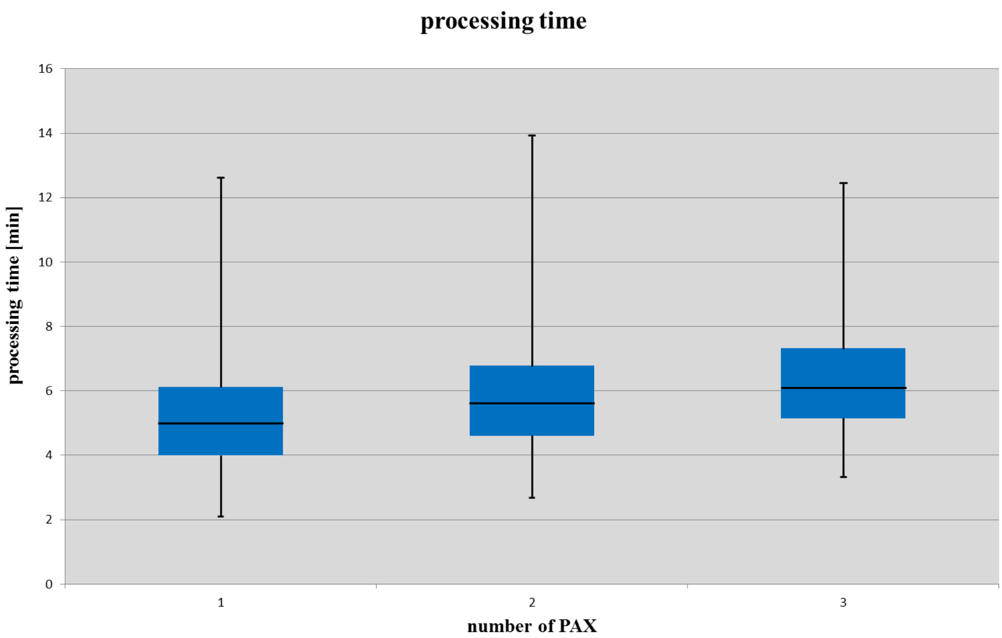

Fig. 6. Processing time for passengers across all simulations.

As expected, the processing time increases with the number of occupants. This increase is only slight though. It is also apparent that the spread of the processing times is considerably larger above the median than below. These two peculiarities can be explained by the fact that there are two vehicle lanes per security checkpoint. The individual security processes for each lane therefore overlap, meaning that the vehicle checks including occupants cannot be observed separately. So the processing times for the respective number of vehicle occupants are not free from overlaps. If a person, for example, has to be checked and there are currently two people from another vehicle from the other lane in the checking process, the person first has to wait until the other two people have passed through the security checkpoint before they can undergo checks themselves. This increases the processing time measured for a security check for one person.

4. Conclusion and outlook

In order to successfully process this approach, the TOMICS simulation software was supplemented by a proprietary simulation logic which makes it possible to simulate the security checks at ferry ports. As there are currently no security checks at German ferry ports, checks meeting German Aviation Security Law were applied. A well-known German ferry terminal served as the model harbour. 10 vehicle lanes and 5 security checkpoints were modelled and simulations were created using parameters such as the ferry timetable. The travel days Monday through Friday were simulated with 100% and 75% capacity utilisations.

The assessment of the simulation results made it clear to what extent security checks at ferry ports affect the traffic flow. The result was long waiting times of up to 160 minutes and a high proportion (39%) of vehicles which did not make it to their ferries on time. These results are not acceptable in reality.

Though in our scenario the security level is high and the costs for security are acceptable the output according to traffic flow is not tolerable. Of course, increasing the number of security checkpoints would improve the traffic situation keeping the security level high, but the costs would increase. In addition to this, the general lack of space at ferry ports make implementing such measures very expensive. Another possibility to improve the traffic flow are less strict security checks on a spot-check basis. The costs will be less in this case, but also the security level would decrease. It becomes clear, that there are least three factors that should be balanced, namely security, cost and traffic flow.

But there are furthermore some actions that can have a positive effect on the traffic without decrease security or increase costs. They can be tested by means of further simulations. One of these actions is an adjustment of the timetable to allow a more even distribution of the ferry departure times. This would achieve a more homogeneous arrival distribution for the vehicles. Regardless of their acceptance by passengers, these measures are not sufficient to mitigate the effects on traffic flow when the ferries are operating at 100% of capacity. Another possibility is to separate the truck checks from the car checks. It would be easier to regulate the arrival times of trucks by allocating slots so that they do not have such a big effect on the cars.

The current state of the art should also be continually kept in mind. Especially technical improvements in the field of vehicle screening can lead to a superior traffic flow and improved security check processes can allow for optimisations in processing times.

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