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Safe Interaction of Automated Forklifts and Humans at Blind Corners in a Warehouse with Infrastructure Sensors

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Abstract. Co-working and interaction of automated systems and humans in a warehouse is a significant challenge of progressing industrial systems' autonomy. Especially, blind corners pose a critical scenario, in which infrastructure-based sensors can provide more safety. The automation of vehicles is usually tied to an argument on improved safety. However, current standards still rely on the awareness of humans to avoid collisions, which is limited at corners with occlusion. Based on the examination of blind corner scenarios in a warehouse, we derive the relevant critical situations. We propose an architecture that uses infrastructure sensors to prevent human-robot collisions at blind corners with respect to automated forklifts. This includes a safety critical function using wireless communication, which sporadically might be unavailable or disturbed. Therefore, the proposed architecture is able to mitigate these faults and gracefully degrades performance if required. Within our extensive evaluation, we use a warehouse simulation to verify our approach and to estimate the impact on an automated forklift's performance.

Keywords: Driverless Industrial Trucks · Blind Corners · Infrastructure Sensors · Warehouse.

1 Introduction

The progress of industrial automation leads to more and more integration of automated systems into today's industrial environments. Whereas previously the ideal procedure to follow was segregating automated machines from human workers, e.g., placing robots in dedicated safety cages, the co-working of humans and machines is an important factor for future competitiveness [23]. For instance, enabling personnel to be in the same area at the same time as automated guided vehicles (AGVs), provides ways to efficiently use the flexibility of humans and carrying power of machines [25].

One example is a warehouse in which AGVs operate alongside workers. Industrial trucks are a major source of accidents within in-house transportation [6]. Additional guidelines for driverless industrial trucks [11], such as AGVs, reduce the inherent risk of human-machine-collisions. In order to not loose advantages of the automation by restricting operation to single areas, the pure local separation of human workers and AGVs cannot be maintained. In these scenarios, AGVs are equipped with safe perception capabilities, e.g., lidars or radars, and have to slow down or come to a complete stop, when obstacles in the surrounding are detected [26]. Additionally, guidelines for human workers should enforce compliance with the given safety rules. One major challenge in a modern warehouse, however, is the limited line of sight, for instance due to walls, shelves, or storage. In this case, corners become a potential point of risk. As AGVs cannot detect occluded objects at such intersecting paths, their application in this area is constrained, i.e. no operation or strongly reduced speed [1]. Human workers also cannot see around the corners and thus, are also in risk of provoking collisions [21]. Specific safety rules, like the rule of waiting at corners before stepping forward, could alleviate such risks, but are at risk of being ignored or overlooked during work. In general, safety mechanisms are more likely to be bypassed, if they are perceived to reduce efficiency [9]. In our work, we target to improve the safe interaction of humans and automated forklifts, which can be seen as a specific kind of AGV, by utilizing sensors of the infrastructure. Specifically, our approach addresses such corner situations, so-called 'blind corners', in warehouses operating automated forklifts. As main contributions, we analyze the problem of blind corners in detail and derive how present solutions manage the safety in such situations. Moreover, we present an architecture and new safety concepts exploiting infrastructure sensors for achieving a safe and efficient interaction of humans and automated forklifts at such critical situations. Our approach is evaluated by thorough simulations of blind corner warehouse situations and analyzing the adherence to safety goals and operation performance. With the results of this paper, we aim for showing how safety can be achieved, even in the presence of potentially unreliable wireless connections, by dynamically adjusting the forklift's performance with respect to the available perception information.

The remainder of this paper is structured as follows. Section 2 presents and formalizes the safety challenges of blind corners in common warehouses and introduces related work. In Section 3, we introduce our approach for infrastructure-based safe interaction of humans and automated forklifts at blind corners. Our extensive evaluation and results of our approach in varying warehouse scenarios are outlined in Section 4, before we conclude the paper in Section 5.

2 Blind Corners in Warehouses

2.1 Definition of Blind Corners

Walls or obstacles near the apex of a corner prevent any direct line of sight to crossing vehicles or humans. This situation is illustrated in Fig. 1. We define a *blind corner* as an intersection or turn that requires an ego vehicle to change its speed to avoid potential collisions, while line of sight is occluded by an obstacle. When approaching a blind corner, the required braking distance determines a safe speed limit until conflicting crossing objects can be excluded [35]. For road intersections, this can lead to a behavior similar to expert drivers [19]. However, compared to a road scenario, the safe deceleration of a forklift [24,30] is lower and walls are often closer. To prevent the slowdown, information about the presence of a human (or other crossing vehicle) must be available much earlier [1].

For example, at a speed of $5\,\frac{\mathrm{m}}{\mathrm{s}}$, braking of a forklift needs to start at a distance d_{brake} of 3.5–6.5 m [30]. Additionally, the automated forklift travels $d_{process}$ while processing inputs. During processing, it needs to detect the intersection and if there is someone in the *conflict area*. Latter is defined by the time the forklift would take to pass the intersection and the passing human's speed:

$$d_{conflict} = v_{other}(d_{process} + d_{brake} + d_{inter} + d_{fl})/v_{fl}. \quad (1)$$

If the conflict area and a margin for detection (d_{detect}) cannot be cleared, the forklift must decelerate to avoid a potential collision. The point for a decision based on line-of-sight [35] is close to the intersection, where the forklift already almost stops, as there is also less space to the occluding wall separating forklift and human. Further, this does not account yet for the whole length of the vehicle to pass. When using infrastructure sensors to avoid unnecessary slow downs of an approaching forklift, the sensors need at least a detection range with radius

$$R > d_{inter} + d_{conflict} + d_{detect}. \quad (2)$$

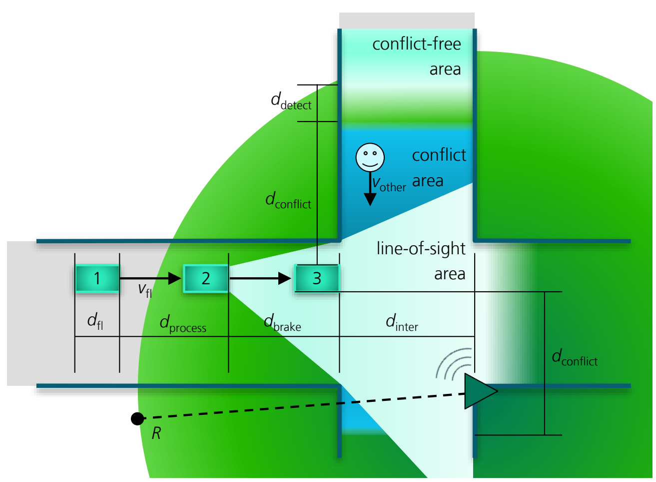

Fig. 1. An automated forklift approaching a blind corner.

2.2 Safety Standards for Driverless Industrial Trucks

As the autonomy of mobile machinery increases, also specific safety standards are being established. However, often there is a gap between requirements of these standards and state-of-the-art, which complicates more gradual paths to develop a system [34]. Within the European Union, laws such as the Machine Directive and national laws for protection of human safety are complemented by ISO and IEC standards that describe general design principles, cover aspects for a wide range of machinery or deal with particular machines [17]. The requirements for unmanned forklifts, AGVs and associated systems are defined by ISO 3691-4 [11].

Four kinds of access zones are defined by this standard. In the **operating zone**, a minimum clearance (i.e. 0.5 m wide) must be provided on both sides of the path and in the direction of travel. An **operating hazard zone**, where a person can be exposed to a hazard, requires audible or visual warnings and a low speed of $0.3\,\frac{\mathrm{m}}{\mathrm{s}}$. Higher speeds like $1.2\,\frac{\mathrm{m}}{\mathrm{s}}$ are only allowed under specific conditions. A **restricted zone** is a physically separated space, like a very narrow aisle, that may be entered only by authorized persons. Without personnel detection means, speed is limited to $0.3\,\frac{\mathrm{m}}{\mathrm{s}}$. Access to enclosed space of a **confined zone** must be restricted to authorized personnel and is only allowed after the movement of trucks was stopped.

In this research, we examine the operation of automated forklifts within an *operating zone*. Therefore, they can go up to their rated speed and we assume a gap between forklift and the next wall of at least 0.5 m. Operation at rated speeds requires personnel detection mechanisms to be active. However, the standard requests a detection of persons in the direction of travel only, which is verified by testing if the forklift detects static cylinders representing legs of a standing worker or the body of a lying worker [11, 13]. The result is that the forklift will not check for workers to its side and everywhere there is a blind corner. Safe interaction between an automated forklift and humans is only provided by the requirement of sufficient space around a forklift, which mitigates some of the more severe outcomes of a collision. Nevertheless, the main burden for avoiding collisions remains with the human. In future however, safety of a technical system is also envisioned to encompass freedom from danger [10]. Therefore, the responsibility of avoiding a collision should be moved from humans to the automated forklift.

2.3 Intersection Cooperation and Coordination

Blind corners are not a new hazard in warehouses. Human drivers of forklifts need to be instructed how to behave safely in such cases, e.g., slowing down, sounding the horn and looking around [4]. A simple flashing light, even when mounted in a highly visible location, might not be sufficient to prevent (near) collisions with a robot at a blind corner, as for example a reported case in October 1994 indicates [8]. Still, light spots or symbols projected into the direction of travel or around the forklift can improve awareness similar to beeper alarms for reversing [3].

Different technologies are currently researched that might enable drivers or autonomous machines in warehouses or on the road to see non-line-of-sight (NLOS) objects, e.g., around a blind corner. Selected examples are: the signal from surveillance cameras can be transformed to create virtual mirrors [12], moving shadows can be observed [20], radars can be used to detect moving objects around the corner [31,33] – possibly with the help of passive reflectors [29], and NLOS imaging can help to reconstruct hidden objects from multiply scattered light of laser sources [22]. Nevertheless, the computational power required to reach a sufficient performance and reliability level, so that safety-relevant decisions can rely on their measures, is just one reason why these technologies are still more a topic of the future.

By including support from infrastructure and infrastructure-based sensors, these problems can be avoided. For example, humans could be located in a warehouse using camera-data [14] or ultra wide band (UWB) technology [25,32] with a precision of at least 15 cm. Further, such a real-time locating system (RTLS) can also be used to predict the paths of workers [15]. Still, the safety integrity of such locating systems needs to be assessed. While at a higher cost, sensors similar to the safety equipment in automated forklifts could be installed at blind corners, to guarantee reliable detection of human workers. In addition, movement data can be collected and help in the creation of spaghetti charts to further analyze and improve safety [2].

Even if infrastructure can reliably identify workers, this information needs to be transferred to the automated forklift. Various methods to centrally coordinate vehicles and avoid collisions exist, e.g., [1,16,26,28]. However, the methods default to denying access to the intersection without connection or require a working connection. While reliability of connections can be improved by using multiple links [27], this also requires more resources. In the remainder of the paper, we detail how monitors for the infrastructure cooperation performance allow to dynamically adjust the forklift's actions to its available information.

3 Infrastructure-Cooperative Autonomous Control

In this section, we propose a novel architecture and compare multiple corresponding safety concepts as solutions for safe and efficient automated forklift operation in a warehouse, where human workers might be present. The description focuses on interactions at blind corner. Safe and efficient operation of autonomous systems in cooperation with humans is usually handled by reducing the machine's speed when humans approach [23]. Blind corners require support from infrastructure to detect human workers efficiently [1]. This includes a safety critical function using wireless communication, which sporadically might be unavailable or disturbed. The architecture which we propose is able to mitigate these faults and automatically adjusts the performance if required. In the next section, we provide a quantitative evaluation of the concept's influences on safety and efficiency, which is intended to help selecting the appropriate safety concept according to different conditions and requirements of warehouse operation.

3.1 Infrastructure-Cooperative Autonomous Control Architecture

This subsection presents our architecture to achieve safe and efficient operation of automated forklifts in a warehouse where human workers can be in proximity. The architecture includes the core AGV tasks [5] and utilizes infrastructure sensors and systems to monitor, predict and estimate the risk of hazardous situations in the warehouse. Additionally, the cooperation of infrastructure and forklift is continuously monitored on both sides to adjust the performance, e.g., the speed of the forklift, if required for safe operation. Figure 2 shows an overview of the proposed infrastructure-cooperative architecture for automated forklifts.

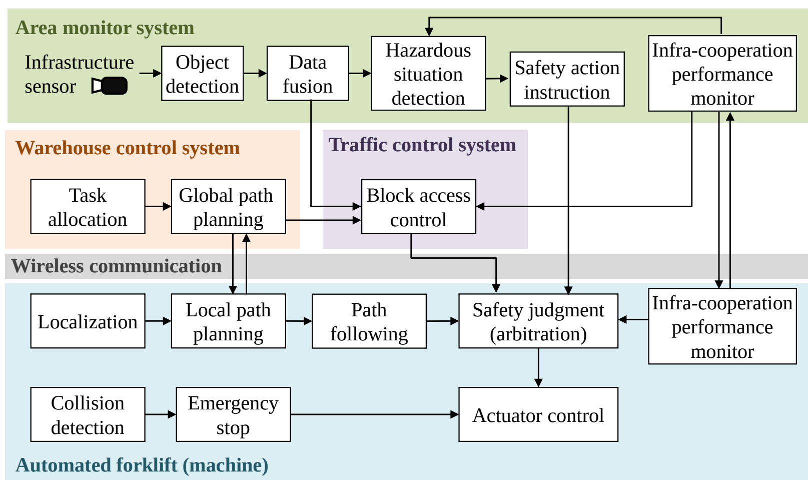

Fig. 2. Infrastructure-Cooperative Autonomous Control Architecture

The **warehouse control system** aims to maximize overall operational efficiency. *Task allocation* assigns tasks to each forklift (and worker) considering overall efficiency, where *global path planning* determines an optimal route for each forklift and task.

The **traffic control system** coordinates the (automated) movement in the warehouse. For example, no collision of machines will occur if only one machine may enter a certain area at the same time. Therefore, *block access control* manages the permissions of machines to enter blocks along their planned paths based on available information, e.g., positions and paths.

The aim of the **area monitor system** is to avoid the collision risk that cannot be prevented by the traffic control system. The system monitors the existence and movement of machines and workers in the warehouse using available infrastructure sensors for *object detection* and *data fusion*. *Hazardous situation detection* recognizes defined safety risks or deviations from rules. The system determines and issues *safety action instructions*. It can request a connected forklift to follow them immediately if a safety risk is observed or prepare the case of a missing connection.

The **automated forklift** is provided with various functions to ensure safe operation of the machine. Based on the position of the forklift identified by *localization*, its trajectory is determined by *local path planning* and *path following* based on the designated route provided by the warehouse control system. *Safety judgment (arbitration)* validates the trajectory and determines a suitable speed that ensures safe operation based on received permissions from traffic control, safety action instructions from area monitor and the reported status of *infra-cooperation performance monitor*. The *collision detection* and *emergency stop* functions implement the personnel detection mechanisms required by current standards, e.g., the ISO 3691-4 [11], using the machine's own sensors.

In brief, the proposed architecture ensures safety in three ways: block permission, area monitor and emergency stop. This structure enables collision avoidance in advance and reduces unnecessary deceleration and stoppage of the automated forklift. The operational efficiency can, thus, be expected to be improved. However, new potential hazards or failures are introduced when the safety critical function uses information from infrastructure systems.

3.2 Infrastructure-Cooperative Autonomous Control Hazards

This subsection examines the potential hazards of including infrastructure information in a safety critical function, like collision avoidance at blind corners from a functional architecture perspective. Therefore, the fault-tree shown in Fig. 3 analyzes the functional interactions of the subsystems and does not consider any hardware or implementation faults.

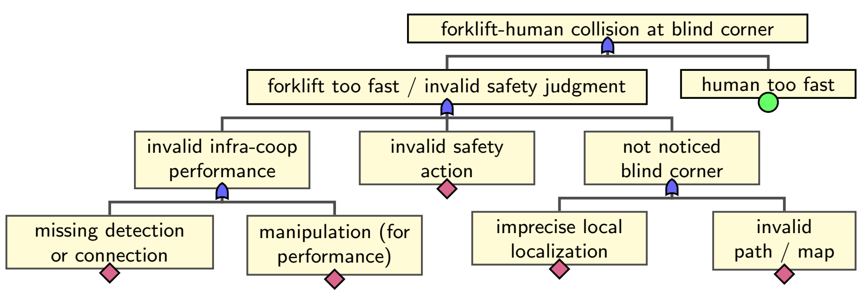

Fig. 3. Fault-tree of forklift-human collision for the functional architecture.

The forklift could be too fast, e.g. by failing to slow down at a blind corner due to making an invalid safety judgment. This can happen if the forklift does not notice the blind corner situation because of an incorrect position; either, because of insufficient localization, or by using an invalid map, which might be outdated or incompatible with the path received from warehouse management. Further, it could be too fast by an invalid safety action or by an invalid monitoring of infra-coop performance. The architecture is designed to handle missing detections and connections gracefully by monitoring. However, manipulation poses an inherent potential safety risk. Manipulation of safety mechanisms is often motivated by improved performance [9]. For example, a human working near an intersection could be spoofing the sensor to prevent forklifts from slowing down. Such cases can be handled safer, if the safety concept allows integrating performance concerns. Besides the forklift, also a faster than anticipated human worker could reach the intersection early, even though he was not in the designated conflict area when the automated forklift had to make its decision.

Besides these functional faults, we identified **the dependability of detection using infrastructure sensors** and the **dependability of wireless communication** between systems as main sources of this hazard.

Sensors and algorithms used for detection in the infrastructure system need to comply with necessary safety levels, e.g., they must be either able to reliably detect the presence of humans in the required range or recognize their inability to do so. The former can be achieved, for example, by using sensors similar to those used on the vehicle to detect humans.

Wireless communication, in the fault-tree contained within *invalid infra-coop performance*, cannot be as easily guaranteed to always work. A loss of connection cannot be avoided perfectly, even with efforts to improve the reliability of wireless communication. Since the proposed architecture requires continual exchange of information between the automated forklifts and the infrastructure systems, a mechanism to continue safe and efficient operation even with a failure in the communication is indispensable.

As a mitigation for this weakness, we introduce a monitoring and recovery mechanism. The infrastructure cooperative performance monitor in Fig. 2 monitors the condition of communication between automated forklift and area monitor. If communication fails longer than a predetermined interval, the forklift can switch to a mitigation mode using its own sensors only [7]. Safety judgment ensures safety for this *conditional selection of personnel detection means protected zones* [11]. However, this might interfere with decisions made by traffic control. As a mitigation measure on the infrastructure side, for example, it is conceivable to regard the loss of communication as a safety risk and notify each function of the situation. The block access control and hazardous situation detection can adapt instructions to other forklifts if necessary. Details of the forklift's local mode will be described together with safety concept in the next subsection.

3.3 Safety Concepts for Safe Interaction of Automated Forklifts and Human Workers at Blind Corners

This subsection presents three safety concepts for safe interaction of the automated forklifts and human workers at blind corners, based on the proposed architecture. Movement of human workers can only be controlled by signals and operational rules. However, they can be ignored or violated for various reasons [3, 4, 8, 10], intentionally or unintentionally. On the other hand, a safety concept suitable for individual warehouses is not always the same.

This research considers the following alternatives as *safety concept (SC)* for safe interaction at blind corners:

- SC0: Stop only for humans detected in direction of travel
- SCA: Decelerate at blind corners and prioritize forklift
- SCB: Utilize infrastructure and prioritize forklift
- SCC: Utilize infrastructure and prioritize person

SC0 uses only the minimum personnel detection mechanism required by ISO 3691-4 [11] outside of confined zones. All other responsibility to avoid collisions at blind corners remains with the worker.

SCA is similar to a conventional operation with human-driven forklifts [4,30] without using infrastructure systems. As operational rule, *persons should pause at intersections, check if a forklift is approaching, and wait for the forklift to pass; and the forklift is allowed to continue slowly.* Even though priority is given to forklifts, they must pass intersections while paying attention to the presence of human workers that could violate the safety rule. As it is difficult for the forklift to detect persons due to blind corners, intersection areas are treated like operating hazard zones and the forklift's speed is limited accordingly. The deceleration helps to avoid collisions, but may unnecessarily hinder efficiency.

SCB utilizes the proposed infrastructure cooperative architecture and prioritizes passage of forklifts. The operational rule for the worker is identical to SCA, but an *automated forklift may continue at normal speed, if there is no worker in the conflict area.* Presence of workers in the *conflict area* is monitored by infrastructure sensors and causes a safety action instruction to slow down for the automated forklift. In addition, operation of the forklift is switched to a *local mode* similar to SCA if a missing safety action instruction or a failed communication is detected, e.g. by using a heartbeat with a rolling counter for the instructions. This safety concept is expected to improve operational efficiency by limiting the situations that require significant deceleration of the forklift. On the other hand, the risk remains that persons violating the rule and stepping into intersections may cause collisions with the slow forklift.

SCC utilizes the proposed infrastructure cooperative architecture and prioritizes passage of human workers. The operational rule is set as follows: *Forklifts check the existence of workers in conflict areas and wait for them to pass; and human workers do not have to stop and can pass freely.* Like in SCB, infrastructure sensors monitor the presence of workers and the forklift can pass at a normal speed in their absence. Also, a *local mode* similar to SCA is used if a missing safety action instruction or a failed communication is detected. The difference between SCC and SCB is the triggered safety action, if a worker is present. In SCC, the forklift is instructed to decelerate, stop and wait for the worker to pass. The forklift can resume passing only after all humans left the conflict area. As priority is given to humans, they cannot violate a rule preferring forklifts. However, unnecessary waiting times for forklifts may occur, especially if a human worker stays near an intersection.

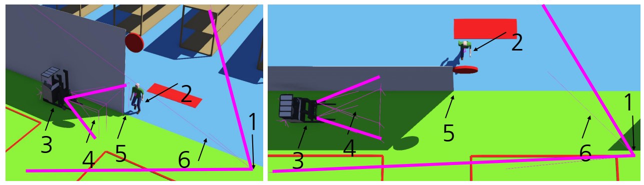

Fig. 4. Overview of the blind corner scenarios used in the simulation: (1) infrastructure camera, (2) human worker, (3) forklift, (4) forklift cameras field of view, (5) blind corner, (6) infrastructure camera field of view.

4 Evaluation

The safety concepts are evaluated in a robotics simulation using Webots [18]. For this, the architecture shown in Fig. 2 was implemented and several scenarios in the warehouse setting have been examined at the intersection shown in Fig. 4. In the simulation, cameras with correct object recognition are used as assumed dependable sensors. A fixed infrastructure sensor covers the *conflict area* of the intersection. It recognizes forklifts, human workers and their positions. If a human is detected in the conflict area, the selected safety action is forwarded to the approaching forklift. Block control and warehouse control system have been replaced with stubs that instruct the forklift to pass the intersection.

The automated forklift is equipped with two sensors, covering the area in front of the forklift and partially on the sides, simulating the personnel detection mechanism required by ISO 3691-4 [11]. In each simulation run, the forklift has to travel 35 m starting 25 m before the intersection. The simulation assumes a rated speed of $5\,\frac{\mathrm{m}}{\mathrm{s}}$ and a value of $3\,\frac{\mathrm{m}}{\mathrm{s}^2}$ for brake and acceleration. For simplicity, the simulated human worker follows a straight path across the intersection and will either pass it, wait before the intersection (but already in conflict area) or not enter the conflict area. To cover all cases where a human and a slow or fast moving forklift would arrive at the intersection at the same time and collide without any further action, 45 different initial distances of the human to the intersection were selected. The resulting scenarios range from the human worker crossing the intersection before the automated forklift to a slow forklift passing before the human can reach the blind corner.

The safety concepts *SC0*, *SCA*, *SCB* and *SCC* have been implemented in the Webots simulation, allowing the comparison of their performance and safety. A shorter **average completion time** indicates a better performance of the system. We only take successfully completed runs into account, i.e., runs with collisions or timeouts (30 s) are excluded. The **number of collisions** indicates the safety of a system – ideally there should be no collisions. Front and side collisions are considered as simplified indication of an accident's severity. Side collisions are less severe and result from humans walking into a visible forklift.

For each safety concept, all possible combinations of communication with infrastructure status and human behavior were taken into account. Table 1 sum-

Table 1. Simulation results: average time of successful completion of task ($t_{avg}[s]$) and number of simulations that finished successfully (F), ended due to timeout (T), ended in front collision (fC) or side collision (sC). Zero values have been omitted for clarity.

Human	Metric	Communication status							
		Off		On		On→Off		Off→On	
		SC0	*SCA/B/C*	*SCB*	*SCC*	*SCB*	*SCC*	*SCB*	*SCC*
passes intersection	t_{avg}	7.3	12.6	8.7	9.1	12.2	12.2	8.8	9.2
	F	29	37	45	45	37	37	45	45
	fC	13	3			3	3		
	sC	3	5			5	5		
waits in conflict area	t_{avg}	7.3	11.7	9.9	7.3	11.4	11.4	10	7.4
	F	45	45	45	18	45	45	45	17
	T				27				28
not present	t_{avg}	7.3	11.7	7.3	7.3	10.9	10.9	7.3	7.3
	F	45	45	45	45	45	45	45	45

marizes the average completion times and the different results for each combination. While there is only a collision risk, if the human crosses the intersection, good performance in the other cases is expected to improve acceptance of a selected safety concept. If communication is off, forklifts ignore all messages from infrastructure. Switching of communication status was timed to impact right before the forklift has to make its decision whether to brake or not. Since the scenarios cover all possible encounters that can be achieved by changing the start positions, we assume that the following observations apply in general to the interaction of an automated forklift and a human worker at a blind corner:

SC0 provides very good performance when there is no risk of collision. The average time of performing a task is 7.3 seconds, which is the best achievable result. However, if the human does not prioritize the forklift and walks into the intersection, more than every third simulation run ended in a collision. This result underlines the motivation that intersections with blind corners require special attention to ensure safety for human-machine cooperation.

SCA results in less front collisions than *SC0*, by slowing down near the blind corner. This concept increases safety by giving the forklift more time to detect a person and stop – only 7 out of 45 runs ended in collisions, including 3 severe accidents. However, it increases the average completion time to almost 12 seconds, as deceleration is performed regardless of a nearby human.

SCB provides very good performance when there is no human in the conflict area and the forklift receives permission to pass the blind corner at maximum rated speed. In these scenarios, this also avoided collisions that could only have happened, if the forklift had slowed down. When needed, slowing down provided sufficient delay for the forklift to detect the human and stop.

In the observed cases, *SCC* provides no significant improvement over *SCB*. However, *SCC* can improve safety in more complex scenarios, e.g., if the human is not moving with constant speed or if multiple humans are present. On the other hand, if a human remains in the conflict area, the forklift will also wait

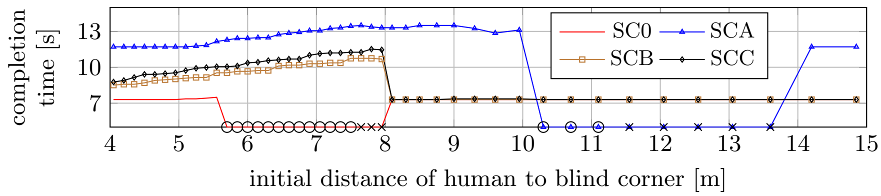

Fig. 5. Forklift completion times for passing humans based on the human's initial position. Circles and crosses mark runs resulting in front or side collisions respectively.

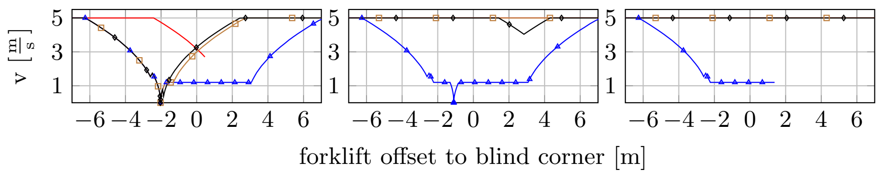

Fig. 6. Speed curves of the forklift for human starting at 6, 9 and 12 m distance.

indefinitely, unless an additional override mechanism is implemented. For both, *SCB* and *SCC*, the forklift gracefully degrades to *SCA*'s safety and performance level, if it receives no information from infrastructure.

The impact of the human's initial position on completion times is shown in Fig. 5. Two areas of potential collisions can be identified in the diagram. If the human is already close to the intersection, he could collide with a quick moving forklift (*SC0*). A slow moving forklift (*SCA*) could collide with a human further away. The dynamic decision being made in *SCB* and *SCC* allows the forklift to avoid these situations by either slowing down for the human to cross (left) or passing the intersection quickly and safely before the worker can reach it (right). For the human starting at distances of 6, 9 and 12 m to the intersection, speed curves of the forklift are shown in Fig. 6 from left to right. In the left diagram, forklifts decelerate at d_{brake} except for *SC0*, for which the emergency brake could not prevent a collision. In the other diagrams, the forklift decelerates only for *SCA*: In the middle, the forklift avoids a collision by stopping, while an inattentive human runs into the forklift's side on the right.

5 Conclusion and Outlook

This paper examines the interactions of automated forklifts and humans at blind corners in a warehouse. We introduce an architecture that includes infrastructure sensors to increase the safety in these situations while having minimal impact on efficiency. We present and compare safety concepts related to this architecture that each address different needs. Clearly, relying only on the forklift's own sensors either poses a high risk for human workers, if the forklift does not slow down at intersections (*SC0*) or suffers a severe performance penalty (*SCA*). Using information from infrastructure sensors (*SCB*), the decision to slow down can be made dynamically, which reduces the impact on performance, even if the connection is not always available. Still, a small risk remains if a slowly approaching automated forklift is ignored. However, instructing forklifts to unconditionally stop for humans (SCC) will lead to unnecessary waiting times.

In the future, a human worker's behavior might be inferred automatically, when it is possible to have more and reliable information, e.g. by an improved prediction that can recognize the human's intention and awareness. In the meantime, such systems could include means for workers to actively yield to forklifts.

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