A scientific approach to get a GRIP on practical robot safety

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This work provides insight into the scientific-ground work for the development of digital safety tools for human-robot interactions; GRIP - Guarding Robot Interaction Performance. GRIP is a digital safety management system under development for human-robot interactions (HRI) in an Industry 4.0 setting. GRIP draws knowledge from different sources to utilize practical, scientific and legal information in a single tool; Storybuilder, HRI-GRIP, and the Machine Directive. Storybuilder deals with the structured recording and analysis of occupational accidents. HRI-GRIP provides a structured ontology of relevant characteristics that affect the outcomes of HRI. The machine directive collates all legal safety requirements for machines and working safely with machines Each of the parts provides a relevant viewpoint for robot-safety and together they provide the basis for a holistic analysis of safe working with robots. With this scientific framework GRIP can operate as a 360° diagnosis tool for the safety assessment of HRI applications on the work floor.

Keywords: HRI, Occupational safety, robots, Machine Directive, Storybuilder, Risk analysis

1. Introduction

One of the characteristics of industry 4.0 is the introduction of cobots or cooperative robots, potentially utilizing the strong points of machines (e.g., accuracy and speed) and of human workers (e.g., flexibility and creativity) in cooperative tasks on the work floor. This paper addresses GRIP - Guarding Robot Interaction Performance a digital safety management system under development for human-robot interactions (HRI) in an Industry 4.0 setting. GRIP has a strong emphasis on the human factors (HF) and occupational safety and health (OSH) side of the interaction. In GRIP the knowledge framework draws from different sources to utilize practical, scientific and legal information in a single tool.

The knowledge framework of GRIP is based on three foundational approaches. The first is Storybuilder which deals with the structured recording and analysis of occupational accidents (RIVM, 2021). Storybuilder is used today for the analysis of occupational accidents by the Dutch labour inspectorate and encapsulates the causal factors for accidents as well as the factors that aggravate the consequences. The second approach is HRI-GRIP based on the input-mediation-output (IMOI) model (Ilgen, Hollenbeck, Johnson & Jundt, 2005). Originally developed to model teamwork, IMOI identifies the relevant characteristics of each team member that affect the cooperation, the states that emerge from the interaction and the eventual output. Here, the framework of IMOI is applied on the 'teamwork' between operator and robot and have expanded upon the model to provide a structured ontology of relevant characteristics that affect the outcomes of HRI. The third approach implemented in GRIP concerns the legislation in relation to machine safety: the Machine Directive (2006/42/EC). The machine directive collates all safety requirements for machines and working safely with machines.

Together these three elements provide a solid base for GRIP with an OSH risks & statistics backbone (Storybuilder), an ontology of relevant HRI characteristics based on scientific literature (HRI-GRIP), and the legal context from the machine directive. In the remainder of this paper, each element will be described, including their role in relation to GRIP as a safety management system for HRI. A hypothetical use case is used to illustrate each element to explain the key issues.

Carrie is an automated guided vehicle (AGV) in a warehouse that moves crates with goods around between storage and shipment. Carrie follows a fixed route in the

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workplace which is demarcated with yellow lines. The route that Carrie and the other AGV's in the warehouse take cross a workplace that is shared with employees who move about regularly. Carrie has two sensor systems, one to follow the designated path, one to detect other AGVs in the vicinity and one to avoid collisions with pedestrians, vehicles and other objects on her route. Because she carries slightly unusually sized packages, a pallet is glued on top of her load-plate. The pallet partially covers her collision avoidance sensors, so she stops at every corner. A piece of duct-tape is affixed to the sensor to circumvent that problem.

Yesterday, an employee was taken to hospital because Carrie ran into him, causing serious abrasions to his knee and lower leg.

2. Theoretical framework

The theoretical framework for GRIP consists of three elements: the Storybuilder model, the HRI-GRIP model and the Machine Directive (2660/42/EC). Storybuilder contributes to the framework for robot safety through the structured modelling of (occupational) accidents. HRI-GRIP contributes through the consistent analysis of human-robot interactions and the Machine Directive offers the legal framework within which robots are admitted to the workplace. The three elements are described in more detail below.

2.1. *Storybuilder*

Storybuilder is the first element. It provides a structured approach to dissect incidents. Storybuilder™ is a database hosted by RIVM, containing data based on the inspection reports from occupational safety incidents (Bellamy et al., 2007; RIVM, 2013). The data base is updated on a yearly basis and currently includes approximately 26,000 occupational accidents that occurred in 1998–2010 and in 2012 (RIVM, 2021). The database lends it name from the fact that the data has been structured in such a way as to allow the reconstruction of individual accidents so that the story is told of how the accident came to be. All stories combined allow the identification of most common sequence of events that can lead to an accident (RIVM 2008) and thus provide valuable insight in which actions should be taken to avoid future accidents.

Based on the data collected in Storybuilder several analytical tools have been developed. One example is Storybuilder-MHCA, which focusses specifically on the data in relation to major hazard chemical accidents (Kooi, Bellamy & Manuel, 2019). Furthermore it provides the numbers for risk calculation (RIVM, 2008) which are at the basis of the Occupational Risk Calculator which can be used to calculate risk profiles for specific jobs or activities (e.g., Aneziris, Papazoglou & Psinias, 2016; Bellamy et al, 2015)

The data in Storybuilder is structured according to a bowtie model (see Figure 1) as described in supporting documents of the RIVM (2013) and scientific work (Bellamy et al., 2007). Storybuilder distinguishes 36 separate accident scenarios based on a list of hazards identified by the Dutch Labour Inspectorate in 2002 (RIVM, 2008). Each accident scenario functions as central events for their own bowtie. For each of these events a number of 'loss of control' events (LCE) are identified, which are the direct causes of the central event. For each of these LCE a number of barriers have been identified whose failure allowed the LCE to take place. For each barrier, specific circumstances or incident factors (IF) are listed that contributed to why the barrier to failed. Storybuilder also includes more generally whether the barrier failed due to the barrier missing, not being used, supervised or maintained (barrier tasks). Subsequently, the data includes whether this task failed due to various management delivery system (DS)s such as procedures, equipment, ergonomics, availability, competence, communication, motivation or conflict resolution. On the level of human factors (HF), Storybuilder distinguishes for the failure of the task 'use of barrier', whether this was the result of a violation, mistake, slip or lapse. Also, Storybuilder contains the data to determine how often the physical shielding was missing during occupational accidents which resolved around the central event 'contact with moving parts from a machine' and which barrier failure was a contributing factor most often in such accidents.

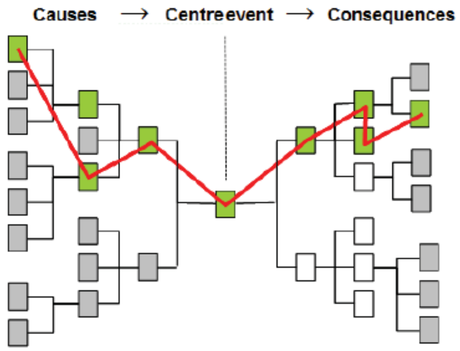

Fig. 1. A sequence of event of a single accident. Taken from RIVM, 2013

For each individual accident a path can be traced across the barriers that failed in that specific case as is illustrated in Figure 1. The path represents an incident narrative in a systematic manner; and so tells the story of the accident.

In the use-case with Carrie the AGV, Storybuilder would identify a 'collision (of pedestrian) with a vehicle' as the central event (CE). This CE occurred due to two failing barriers: a lack of visual contact (of the AGV concerning the employee) resulting in the vehicle not stopping in time (a loss of control event (LCE) on the left-hand side of the CE) and failure to evade the vehicle by the employee resulting in an aggravation of the situation (a LCE on the right-hand side of the CE). Next, Storybuilder would contain some information on why the barriers failed as they did. For example, an inspection would come to the conclusion that the barrier 'visual contact' failed not because there was no visual sensor on the AGV but the barrier wasn't used (Which, in Storybuilder terminology constitutes a failing Task). Next, they might conclude that the barrier wasn't used because of conflict resolution between safe and fast transportation of unusually sized packages (which constitutes the failure of a delivery system: DS). The taping of the sensor due to oversized loads would constitute a routine violation (a human factor: HF). Similarly, the second barrier 'capacity to evade the vehicle' may not have been used (Task), due to a reduced motivation, or alertness, (DS) of the employee as he was in a hurry (an influencing factor: IF).

Viewing the robot-use case with Carrie from the perspective provided by Storybuilder offers a consistent framework for recreating what happened. When similar incidents are reports with AVG's it would be possible to compare those events and identify common failure modes as well as an insight in why certain events unfolded. But the findings could even be more generic; perhaps gluing pallets on top of other vehicles happens a lot? In the next section the second approach, HRI-GRIP, will be discussed which is specifically included in GRIP to identify the most important characteristics that can affect the outcome of a human-robot collaboration.

2.2. *HRI-GRIP*

HRI-GRIP provides a structured ontology of relevant characteristics that affect the outcome of human robot interactions (HRI). HRI-GRIP is based on the theoretical IMOI-model and HTO-model populated with categorized HRI and OSH characteristics. This offers a systematic overview of concerns for safety and productivity in human robot interaction and shapes the blueprint for the holistic safety meta-model of the digital tools within GRIP. In order to model human-robot interaction, it is not sufficient to only look at the individual factors. Instead, it is more efficient to look at all elements and dynamics of the interaction: a 360° diagnosis. To facilitate the development of this holistic model, two existing models were combined with the inclusion of new categories for the HRI and OSH characteristics.

Given that human-robot interaction starts to look more and more like human-human teamwork, it is only natural to search for a theoretical model that carputers the fullness thereof. The IMOI model (Ilgen et al., 2005, Mathieu, Maynard, Rap & Gilson, 2008) is often used to model teamwork (Jaca, Viles, Tanco, Mateo & Santos, 2013). As such this model has been used for human-robot interaction before (e.g., You and Robert, 2017). The IMOI model is based on a review of studies about effectiveness of teams. The principles of IMOI were derived from, and extended upon, the work of McGrath (1964) who expressed team performance as Inputs that lead to Prosses that in turn result in Outcomes (I-P-O). This I-P-O model had three main issues: it lacks influencing factors in teamwork that are not processes; it does not include the dynamic nature of teamwork; the model has a linear nature of one category influencing the next, while in reality e.g. processes can interact with inputs or other process. Therefore, Ilgen and colleagues (2005) defined the IMOI model consisting of Input, Mediator, Output and Input, where the M replaces the P, the late "I" explicitly invokes feedback loops and nonlinear behaviour. The model was later updated by Mathieu and colleagues (2008). This model fits well to the complex, dynamic interactions that human-robot interaction brings.

The system approach requires not only the interaction between the human and the robot (i.e. technology), but also the environment (e.g. the organization) at which they work (Kuhlmann,1981). Berglund and colleagues (2020) summarized the idea behind the model: Despite the best efforts in design machines that are safe, even in degraded mode, operators do not always react as expected. This could be due to numerous reasons, like education, a too high/too low mental load, being tired, etc. And still, if the operator would react perfect to the machine, the organisation (or actually its ´safety culture´) itself could hamper safety performance. For example, operators being disciplined for errors they make, which can lead to a poor safety culture where errors are obfuscated. Each of these three system levels (HTO) can thus deliver input characteristics that affect the system's barriers and safeguards to prevent accidents to occur. In this work, the HTO model was modified to fit the HRI context, instead using a human, robot and environment (HRE)-model.

In addition to the IMOI and HRE framework, three performance categories are included in the model that distinguish different types of safety-influencing elements: Hardware, Software and Mindware. In short, hardware refers to physical and technical characteristics, software is about knowledge and (underlying) processes or procedures, and mindware is about the attitude and experience. These categories form a matrix with the IMOI and HRE categories that structures OSH inputs, mediators and outputs for human-robot interactions forming the scientific HRI-GRIP part of our framework (see Table 1).

The IMOI approach to HRI is described to a greater extent in a different paper(Steijn et al., 2020), therefore this paper will not go into further detail to explain the contribution of the IMOI model for human-robot interactions. The use is demonstrated with the use case about Carrie the AGV.

Carrie will go through a commissioning phase before being deployed. The robot is designed with collision avoidance sensors (robot hardware inputs). The fact that she comes with a name: Carrie, suggests a certain level of personification (robot mindware input). Further it can be assumed that the workers have the right training (human software input) to understand the interfaces/responses and documentation of the robot (robot software inputs) and the meaning of the yellow lines in the workplace (environment hardware input). Carrie reduces the physical workload for humans (hardware mediator) and gives clear signals in interaction which provides the works with a good situational awareness (software mediator) which all contributes to a comfortable workload and job quality (mindware mediators).

Table 1. The underlying framework for HRI-GRIP

	Human Input	**Robot Input**	**Environment Input**	**Mediator**	**Output**
Hardware	*Physical factors and capabilities of the human to perform during the interaction*	*Characteristics affecting the physical factors and capabilities of the human*	*Characteristics affecting the physical factors and capabilities of the human*	*Physical workload and workflow during interaction*	
Software	*Cognitive factors and capabilities of the human to oversee the interaction*	*Characteristics affecting the cognitive factors and capabilities of the human*	*Characteristics affecting the cognitive factors and capabilities of the human*	*Cognitive workload and situational awareness of the human during interaction*	*Optimal HRI which is efficient.*
Mindware	*The human experience and perception of the interaction*	*Characteristics affecting the human experience and perception of the interaction*	*Characteristics affecting the human experience and perception of the interaction*	*Perceived workload, job quality and complacency by human during interaction*	

During operation, things change dynamically. Trust (human mindware input) in Carrie increases, and she starts to transport more and more unusually sized packages. This increasing task complexity (environment hardware input) and improves efficiency (output).

The accident demonstrates that trust has increased to the extent that and the attitude towards her has changed (human mindware inputs) which increased complacency (mindware mediator) and affected vigilance/awareness (human software input). The pallet glued on top of her load-plate makes her stop at every corner which hampers the workflow (hardware mediator) and degrades efficiency (output). This increases time pressure (environment hardware input), stress (human mindware input) and perceived workload (mindware mediator). In the end, the sensor is duct-taped (robot hardware input) to circumvent the issues and maintain efficiency (output).

This narrative in the use case, when put into perspective from the HRI-GRIP, shows not just that something went wrong but helps explain the changes in inputs, outputs and hardware and mindware. So, the HRI-GRIP model adds nuance to the hard facts in the Storybuilder narrative.

2.2. *Machine Directive*

With some understanding of what went wrong and how changes in the interaction between humans and robots it is important to understand what went wrong from a legal perspective. Although there is a number of frameworks to choose from The Machine Directive is the most relevant; it prescribes the most rigorous safety analysis for machines like Carrie. The directive 2006/42/EC on machinery, otherwise known as the machine directive, stipulates under what conditions a machine is deemed safe enough for use in the European Union. Robot manufacturers and integrators (that combine machines into larger machines) need to demonstrate that their products are safe for use and that the essential health and safety requirements (EHSRs) are met. The essential requirements stipulate that hazards to man should be eliminated, mitigated with protective measures or accepted as residual risk under the condition that users are dealt with in local occupational health and safety solutions. Mostly that means that end users are informed about training requirements, procedures for operation, maintenance requirements or protective equipment. That information is laid down in an instruction manual; this document is mandated by the Machine Directive. For this use case this means that Carrie cannot be used in Europe if it cannot be demonstrated that adequate efforts were made to ensure that she is safe, nor without a proper risk analysis performed nor without an instruction manual.

The safety assessment performed in the cadre of the Machine Directive is based on risk analysis on the EHSR’s. That means that the following risks have to be assessed for Carrie’s assessment: mechanical hazards, electricity, high temperatures, fire and explosions, noise, vibrations, radiation, lasers, hazardous materials and slips-trip-falls. Arguably, fire and explosions or radiation are not relevant for an AGV so they can be eliminated from the risk analysis but when mechanical, electrical and slip-trip-falls are left out they lead to serious shortcomings in the risk analysis (which would prevent Carrie from ever reaching the market). Specific machine functions need to be assessed as well. The control system is an important one. Especially since Carrie is a semi-autonomous system that would require considerable attention. Equally the interactions that humans may have as operators, including handling, lighting, ergonomics, and seating need to be addressed. When the risk analysis on Carrie are performed, the relevant risks and scenarios, safety devices, work protocols and maintenance schedules need to be clear.

Another aspect that is crucial is the description of: residual risks. Residual risks are those risks that are deemed too to develop safety protections for (e.g. abrasion of the wheels due to acids), those risks that cannot be eliminated (e.g. because they constitute an inherent function of the machine: Carrie moves around so collisions cannot be excluded) and, fundamentally, risks that are as yet unknown. The risk analysis techniques vary depending on the complexity of the machine or a function. Methods such as Fine and Kinney, FMEA & FTA. Critical applications, such as Carrie's control systems, require deeper analysis such as a quantitative risk analysis (QRA) based on Markov models. As the control system is an IT system, there will have to be adequate attention for cyber-security (Steijn, Luiijf & van der Beek, 2016) as well as safety implications for Artificial Intelligence (Jansen, Steijn, van der Beek, Janssens & Kwantes, 2020). Manufacturers have some leeway in choosing their risk analysis techniques but robots as complex machines, and Carrie as an AGV share the working space with humans and require rigidity in their approach. The risk analysis should also include known elements of the work-environment in which they are placed and prevent against misuse. The risk analysis, complete with a comprehensive description of the robot and its control systems, mitigating events and residual risks, test reports and other pieces of evidence have to be documented in a safety report which is called a technical description (TD).

In order to instil rigor into the risk analysis conformity assessment bodies (CAB's) inspect the TD and decide whether the machine (and its description in the TD) conform with the requirements set out in the Machine Directive. The assessment may include a design examination and a type examination where a prototype is tested. In the latter case a prototype for Carrie will have been tested as part of the assessment. When the robot is safe and adheres to the EHSR's conditions a CAB issues a declaration of conformity that allows the manufacturer or integrator to affix a CE mark on the machine which is required to trade it in the EU. CAB's are commercial enterprises charged with represent public interest and, are accountable to national authorities. They have to be independent bodies and must be established in a member state which, in turn, is required to assess their suitability for the task. CAB organizations employ seasoned safety and risk professionals for their assessments and are often important players in discussions about robot safety.

Crucially, it is mandated that an instruction manual accompanies the machine so that end-users are warned about residual risks and instructed on how to work safely with the machine. For Carrie, that means that end-users understand what they can do with her, what they cannot and how she should be maintained. Carrie should only be put on the market with a) a valid declaration of conformity and b) an instruction manual for the user. In this use case that means that the end-user, the company that bought Carrie should design their workplace according to the specifications in the instruction manual and should have access to that manual; preferably accessible for anyone that would need to see it from a professional capacity within the company (such as the safety expert) or someone working with her.

Ultimately, the machine is put to work in a workplace. Employees have to work with the machine and may interact with them on a daily basis. But worker safety is covered in a different legal regime: Framework Directive (89/391/EEC) on the safety and health of workers. This framework demands that risk assessments are performed for the workplace; this risk assessment is fundamentally different from the one in the Machine Directive and the handover is the instruction manual. Neither the manufacturer of robots nor integrators are required to share the risk analysis or the TD so end users only have the instruction manual to go on for their workplace risk analysis. That means that safety experts in the company employing Carrie need to make a local risk assessment where the instruction manual for Carrie was an input. The warnings, tasks and safety rules in the instruction manual have to become an integral part of the local OSH risk analysis. If performed well, that means that one of the rules is probably that nothing may be changed on Carrie that could hamper her operation. Generally speaking, the instruction manual alone does not provide much transparency in the risks associated with the machine (only the residual risks need be addressed). Manufacturers or CAB's offer services for the development of OHS safety programs which helps cover that handicap.

When the whole process is performed Carrie can be put to work in the workplace. In this case autonomously carrying loads from one place to the other. As she is designed to carry pallets in the first place it may not be a problem if she carries slightly oversized pallets but when a pallet is affixed she is altered as a machine. The pallet is not part of the design and the risk analyses do not cover the risks associated with it. Technically speaking, the machine is a new machine and the person or company that affixes the pallet becomes the manufacturer for the new machine which comes with all the responsibility of the Machine Directive. So from the perspective of the machine directive, the point where staff affix the pallet without going through the process of certification is where an oversight takes place (and not at the time of the accident). Note that the affixing the plate itself is not necessarily impossible; system integrators alter and combine machines and affixing a pallet could actually be acceptable, but it is allowed in the workplace only after the safety review and certification have taken place. But for employees on the workplace it might not be apparent just how far-fetching the consequences may be for making small alterations to the robot. But In this use case a sensor is taped as well. That has to be a violation of a safety rule as the collision avoidance has a safety function. The sensor performs a critical safety function and no doubt, the instruction manual says you shouldn't do that. So this would be the more critical error in relation to the machine directive; and again, it takes place long before the actual accident takes place. So, even if the changes that workers made to Carrie seem small, they are in violation with the Machine Directive and local OSH regulations following from it.

3. Discussion

This work describes the main scientific constituents to analyse safe work with cobots and intelligent robots. These three parts are the most relevant in understanding the complications of working with futuristic robots and how to assure worker safety in OSH programmes. They are i) an accident model in the shape of the Storybuilder product and its scientific basis in risk modelling; ii) the HRI-GRIP tool that deals with human robot interactions; and iii) the legal framework in the shape of the machine directive;. Each of the parts provides a relevant viewpoint for robot-safety and together they provide the basis for a holistic analysis of safe working with robots. The principles are illustrated with a use case for an AGV robot: Carrie.

The perspective from Storybuilder is that a number of safety barriers were breached that allowed the accident to happen. This is not limited to affixing the plate or taping the sensors. The Storybuilder approach should also show that the robot is often burdened with a too heavy load. That people have not been instructed properly about handling the robot, and perhaps even that the company did not have a proper OSH regulations in place. In short, Storybuilder offers a more in-depth analysis in a structured way; and because of that structured approach it is also possible to check whether similar accidents have happened in other companies as well with AGV’s, with overloading, with man-machine collisions or with altered machinery. All of that helps understand whether the incident with Carrie is a one-off incident or something that actually occurs very commonly.

The HMI-GRIP model provides insight into why the changes are made. By addressing the nature of the interactions it shows that changes in production targets and trust between man and machine paves the way to DIY improvements that solve a local problem but insidiously increase the risks. The width of the model makes it sensitive to many shifts in the interactions as well as map out the consequences for OSH management.

The HMI-GRIP model canvasses all kinds of interactions between humans and machines which makes it the backbone for the development of the analysis tool for robot safety. By putting the HMI model central the OSH analysis tool puts the human and its interaction central to the OSH analysis. The addition of Storybuilder is that it adds an opportunity to investigate underlying safety flaws in the interactions. It does so by offering a scientific framework for understanding accidents but it also offers opportunities to compare with other incidents where conditions might have been the same. The Machine Directive offers boundary conditions to the model. It does not provide much insight into the accident but it clarifies where exactly the safety of the machine and/or the assurance mechanisms are breached. Of course, humans have a role in breaching the boundaries but if the focus were on human error alone, it is easy to overlook that the machine is actually the source of the risks.

Finally, the Machine Directives clarifies which acts are the one that constitute deviance from legal guidance. In this use case it is the moment when staff decide to glue a plate onto the robot and tape-off the detection sensor. Legally speaking, affixing a plate to the robot makes the person or company that allows it a manufacturer that has to go through all the steps of machine certification as prescribed by the machine directive. But often, local staff are unaware of such ramifications of seemingly simple alterations. The taping of sensors also constitutes a safety-offence but it is different in nature; it is simply a safety violation (or oversight) because it is hard to see that the machine would pass any safety assessment process without those sensors. Affixing the plate is therefore the more important transgression but it can take a long time before the actual accident happens. In some ways, it creates a latent condition for accidents by altering the machine.

The described theoretical framework allows the GRIP tool to offer a 360° diagnosis. It is beyond the scope of this paper to describe the tools that are under development in detail but the general approach for tool development can be divested. The development takes place in three steps, the first being the development of the OSH model. In this particular the factors addressed by the HMR-RGIP model, Storybuilder and the machine directive are captured in generic bowties (following Storybuilder’s example). These bow-ties are designed to cover as many risks, threats, barriers and escalation factors as possible. These bow-ties are one GRIP tool but they also provide the back-bone for the development of additional tools.

The second step is the development of OSH safety assessment tool. Safety assessment tools are standard instruments in OSH management and fit well into the normal business process for OSH safety experts. In this case, a questionnaire is developed that does two things at the same time: i) assess whether safety-sensitive elements of the HMI model appear locally in the workplace and ii) assess whether safety barriers are in place and operating. The design of the questionnaire is a balance between what is practical for OSH managers and still as complete as possible in relation to HMI and safety barriers. At the time of writing this paper, the discussion about the tool has not (yet) come to a stable questionnaire but it is expected soon. With a stable set of GRIP safety questions, a digital tool is developed that offers the questions through a web-interface and provides feedback in a graphical representation (known as Risk Rounder or Profile Wheels (Kalache et. al 2019)).

One aspect of the questionnaire is that it asks whether key safety controls are in place in the workplace. With those questions it relatively straightforward to cut out parts of the generic bow-Tie made in step 1. With very little effort a local OSH bow-tie can be created (in fact, most of it can be made automatically) which forms the basis for the safety management system. It is projected that the monitoring system could be a chat-bot that make it easier for staff to report relevant incidents. That work will be published later this year.

Together, these tools, allow end-users of robots in workplaces and their OSH officers to gain easy access to the latest in robot safety through a web-portal. As data is collected digitally, it is possible to identify common faults across industries and identify whether some influencing factors are more important than others. The gathered data enables to generate the profile wheel providing an instant overview of the current safety state of the human-robot interaction. The profile wheel indicate the status of the main categories such that the end-user can easily identify the highest risks

4. Conclusion

Following the Industry 4.0 revolution, industries are increasingly introducing cooperative robots in the workplace, seeking to use the strong points of machines (e.g., accuracy and speed) and of human workers (e.g., flexibility and creativity) in cooperative tasks on the work floor. But the safety-impact is not always obvious for corporations and there is a call for a systematic safety analysis that is grounded in scientific theory. This work provides insight into the scientific-groundwork for the development of digital safety tools for human-robot interactions. This paper addresses GRIP - Guarding Robot Interaction Performance, a digital safety management system under development for human-robot interactions (HRI) in an Industry 4.0 setting. GRIP has a strong emphasis on the human factors (HF) and occupational safety and health (OSH) side of the interaction. In GRIP the knowledge framework draws from different sources to utilize practical, scientific and legal information in a single toolset. viz.: HRI-GRIP which finds its origin in the IMOI model, the Storybuilder and the machine directive. The integration of these instruments provide a solid scientific basis for safety assessment of robots in the workplace.

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