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SELF-REPORTED BIG DATA FOR GOVERNANCE OF THE OCCUPATIONAL HEALTH AND SAFETY SYSTEM

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Abstract Enterprises' dilemma to focus on legal compliance or safety has been widely presented in literature. This duality has also created or amplified a number of deficiencies in the inspection system. In this paper, it is argued that collection and exchange of big data on compliance and incidents between enterprises and the authorities is required to converge compliance and safety priorities, along with a necessary shift from compliance control to compliance management and from self-regulation to regulated self-reporting. Research presented in this paper aimed to develop the necessary means to support workplace risk governance in this direction. It started with the development of a conceptual model, linking legal measures to workplace risks. To apply this model, a framework was developed to identify and structure some thousands of risks and prevention measures in workplaces. This framework was codified in a web application to demonstrate its applicability and practicality. This application is designed as a standardized structured interface for self-reporting of compliance and incident data from enterprises to authorities, providing automatic feedback and support to compliance management. The proposed scheme could improve objectivity, transparency and equality, also supporting evidence-based policy making and research..

Keywords: Compliance; occupational risk; big data; labor inspection; risk assessment.

1. INTRODUCTION

1.1. Safety and Compliance

Occupational risk has traditionally been an area of specific interest. Cost externalities are particularly intense [1], along with power asymmetry between the main beneficiary (worker) and the main cost bearer (employer) of safe working conditions, making market forces unreliable to efficiently regulate occupational risk [2].

This weakness was attempted to be covered by State intervention, either in the form of economic incentives (mainly insurance) or legislation [3]. Relevant legislation has been quite extended, sometimes reaching to detailed specifications (measures). This regulatory intervention implies an assumption that safety is a function of compliance to organizational and technical measures specified by legislation.

Although measures specified in legislation are well grounded on research and experience, and violations of them can be found in most cases of injuries [4], they cannot cover all aspects of occupational risk, so as to assume that compliance and safety coincide. Moreover, despite its extent,

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legislation sometimes remains unclear or insufficient to provide coverage [5] or "outdated compared to the latest innovations" [6].

Nevertheless, enterprises' safety is officially assessed (either before or after accidents) on the basis of their compliance, which prioritizes compliance compared to safety practices [7]. Hence, assessment of compliance (not to mention assessment of safety) depends to a great extent on the discretion of inspectors, thus involving elements of subjectivity, such as "routine conceptions of 'risks', 'accidents', 'problems', and so on" [8], "familiarity and individual preference" [9], "values, visions of their work, experience and uses" [7], or "certain culture and views of what is appropriate or not" [10].

Conciliation between inspectors and enterprises is another important issue. Enforcement style is described as a two-dimensional model including facilitation and formalism [11]. Although the threat of enforcement is considered as a requirement for the success of an occupational risk management scheme [12], facilitation is a generally preferable approach that may include persuasion [13] and education [14] of the employers, particularly in small enterprises [15], where lack of knowledge on safety is more intense, although deficiencies might also be present in training of inspectors themselves [16].

Generally, neither regulation, nor inspections appear to be sufficient by themselves. Common legislation in EU countries did not lead to common levels of safety [17], whereas there is no sufficient evidence that labor inspections actually reduce the incidence of occupational injuries ([18], [19]), which is their ultimate goal.

Available resources for inspection [16] are another important deficiency of the system, leading to a usually low frequency of inspections [20]. Hence, it is commonly argued that "the chances to get caught seem to be relatively small" [12]. Moreover, this issue cannot be sufficiently solved by targeted inspection efforts against unwilling employers [21].

It is a basic thesis of this paper that many of these deficiencies are due to the absence of an official model linking explicitly compliance to safety and limited exchange of information between enterprises and the authorities.

A system based on such a model would focus on the consequences of violations, rather than violations themselves [22], comparing real data with the existing legal measures [5] and calculating leading indicators that provide a forecast of future performance [23], rather than recording non-compliances in accidents, that are indicators of something that has already happened [24].

Moreover, the existence such an official model could improve conciliation and facilitation, reducing vagueness and different interpretations of legislation. If it were integrated into a digital application, it could also reduce the administrative workload that is described as an important problem by the European Committee of Senior Labor Inspectors [16]. Finally, it could provide a universal and real-time picture of compliance and safety, providing huge amounts of data and evidence-based information.

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Such a system would require extraction and exchange of big data, which is described in Paragraph 1.2.

1.2 Big Data for Occupational Risk Governance

Enterprises are complex and dynamic systems, where human activity, material factors and processes interact and evolve. This complexity becomes more intense as modern production systems become more lean, flexible and interactive [25]. In the spirit of Ashby's Law of Requisite Variety [26], it takes a proportionally sophisticated model to govern such a system.

Effective analysis of modern workplace risks requires rigorous analysis of information coming from numerous sources of data of different types [27]. The necessity and nature of this data exchange, which corresponds to the "3V's" (Volume, Variety, Velocity) of the definition of big data [28] is explained in this Paragraph.

Volume is the first feature. The number of safety measures that affect any single risk is particularly large. Although incidents are intuitively attributed to a few missing measures only, a systematic analysis identifies a large number of factors that affect the situation. Hence, only an exhaustive and common list of required measures can ensure that all safety efforts against a risk are assessed sufficiently and equally for all enterprises.

Variety is the second feature. In order to have common standards for inspections of enterprises of different sectors and sizes, variety in the standard is self-evident. Information for compliance data has to be processed and filtered (i.e. segregated) at an initial stage, which increases the variety of data by producing secondary data.

Velocity is the third feature. Use of leading instead of lagging indicators does not only have to do with the nature (compliance rather than incidents) but also with timeliness of this compliance data. Enterprises are dynamic entities, with elements that continuously change or evolve (e.g. tear and wear, substitutions, interventions, etc.). Information about safety is relevant only when it is timely and reflects the current situation [29].

This kind of information can only be adequately exchanged and processed through standardized software that can provide immediate feedback to enterprises. When this information comes from inevitably rare on-site inspections, it cannot be assured to be massive, holistic, objective, uniform or comparable, and it reflects compliance in the past, which might not be relevant at the present.

The idea of using big data for health and safety management is not novel [25]. However, this paper presents a certain approach for use of big data that can be directly implemented. The proposed approach in this research is a first step in this direction, being conventional, in terms that basic data is a result of manual observation and reporting. Transmission of non-manually observed and reported information might soon be applicable through Internet-of-Things sensors [30], particularly for safety-critical operations, leading to automation and a higher level of performance of the system in all aspects.

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Research presented in this paper was aiming to create a complete system to address these issues for compliance inspection. It started with the development of a conceptual model, linking legal measures to occupational risks. To apply this model, a framework was developed to identify and structure some thousands of risks and prevention measures in workplaces. Finally, this framework was codified in a web application to demonstrate its applicability and practicality.

2. METHODOLOGY

2.1. The Model for Workplace Risk

This research started with the definition of a simple conceptual model to link compliance with safety, based on Eurostat's taxonomy of European Statistics for Accident at Work (ESAW) [31]. To standardize the selection of risks the "Contact" level of ESAW is used, with some necessary practical adjustments and inclusion of harmful factors for health (noise, vibrations, radiation, etc.) At this level, the ESAW taxonomy includes all kinds of accidents that are officially recognized as causes of occupational injuries.

The preconditions (left side of Figure 1) can lead to the occurrence of the risk and define its likelihood. Prevention measures that could affect any of these preconditions (likelihood/prevention domain) could actually reduce its aggregate likelihood.

On the other side, certain conditions could affect the severity given the occurrence of the risk. Hence, measures that could affect this side (impact/mitigation domain) could actually reduce its impact.

Measures specified by legislation, as well as other measures and conditions too, could affect either one domain (or both), reducing either likelihood or impact (or both). This effect was attempted to be quantified as follows. A predefined default value of likelihood ($p_{0,i}$) and impact ($s_{0,i}$) for each risk (r_i) was assumed (inherent risk), which can range up to 50% upwards or downwards, depending on the effect of related safety measures. The effect of each related measure is weighed depending on its actual effect in the examined risk. The weighing factors for likelihood ($wp_{i,j}$) and impact ($ws_{i,j}$) of the measure m_i are different for every risk j that is affected by this measure. Measures (m_i) can take values -1 (non-existing), 0 (irrelevant) or 1 (existing).

Likelihood (p_i) and impact (s_i) of the risk r_i, are calculated as follows:

$$p_i = p_{0,i} + wp_{1,i}m_1 + wp_{2,i}m_2 + \ldots, \quad \text{where } 0.5p_{0,i} < p_i < 1.5p_{0,i} \quad (1)$$

$$s_i = s_{0,i} + ws_{1,i}m_1 + ws_{2,i}m_2 + \ldots, \quad \text{where } 0.5s_{0,i} < s_i < 1.5s_{0,i} \quad (2)$$

Alternativeness, complementarity, incompatibility or non-linear combined effect of different measures were taken into account by ad hoc interventions (parametrization) on these formulae.

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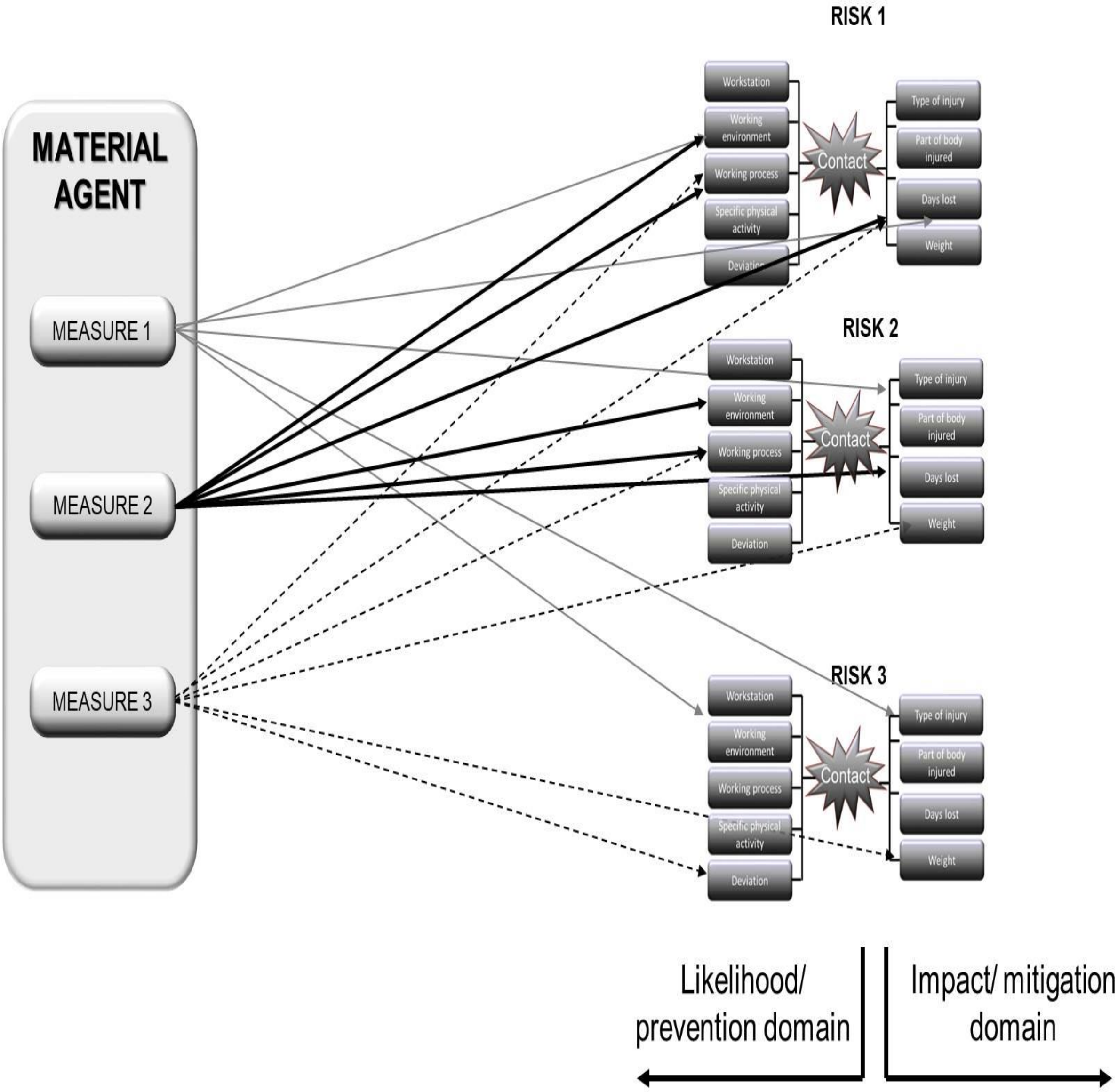

Figure 1. The workplace risk model

2.2 The framework

The next step was the creation of a framework to host this model and make it operable, by finding a way to identify and structure risks and protective measures to be linked by the model. Following the ESAW approach, material agents (infrastructures and materials) were used as the structural unit of the framework. The main assumption behind this choice is that every risk can be linked to a material agent. This linkage is in terms of location rather than causality. It is only used as means of systematic risk identification.

The material agent taxonomy of ESAW was properly analyzed and adjusted for practical reasons, identifying 310 types of key material agents with about 1400 options for special features (e.g. powder, water, gas or foam for the material agent "fire extinguisher"), practically allowing for tens of

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thousands of variations of material agents. These material agents were systematically apposed against the risk taxonomy (the modified "Contact" level of ESAW) in order to identify all possible safety risks in each material agent.

For harmful factors affecting health (physical, chemical, biological and ergonomic, but not psychosocial that cannot be assessed in this framework) the same approach applies, as the risk of exposure to these factors is assessed based on the existing parameters and measures in place. However, for those factors that Threshold Limit Values (TLV) apply (noise, vibrations, inhalable chemical substances), there is an option to declare results of sampling measurements below relevant TLVs to reduce or eliminate the assessment of the respective risk.

Extended research in literature, legislation, suppliers' manuals, ISO standards, etc. followed, aiming to identify, link and weigh safety measures related to each risk of each material agent. A set of workplace risk models, with the relevant formulae (one model for each risk) were created for each material agent. Further parametrization allows for differentiation in relevance, alternativeness, default values, etc. for additional special features of each material agent.

Although the identified material agents cover all usual cases in workplaces, an option for adding new material agents was added in the same structured way to maintain standardization and digitation potential. Having identified and listed all material agents and all possible risks associated with each and every material agent, all risks can be assumed to have been identified and taken into account (with provisions for further improvement).

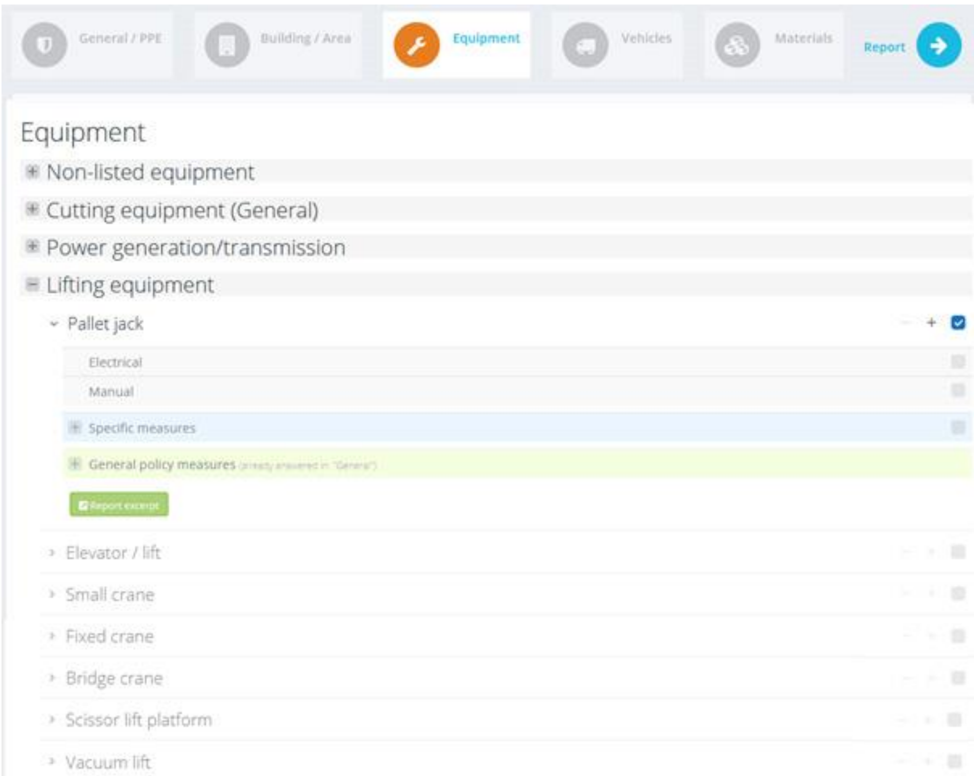

Figure 2. Example of list of material agents.

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3. RESULTS

Such an approach can only be operational if supported by a web-application that will facilitate the collection of compliance data and will assess its impact on safety. This application was the final result of the research conducted. It has to be emphasized that this software application was developed to serve this framework only and not to be used as a workplace risk assessment or management application from enterprise's aspect.

The web-application reflects the structure of the framework. For each material agent, a module including the safety measures and risks that are relevant was created, along with the formulae that link them (for likelihood and impact separately).

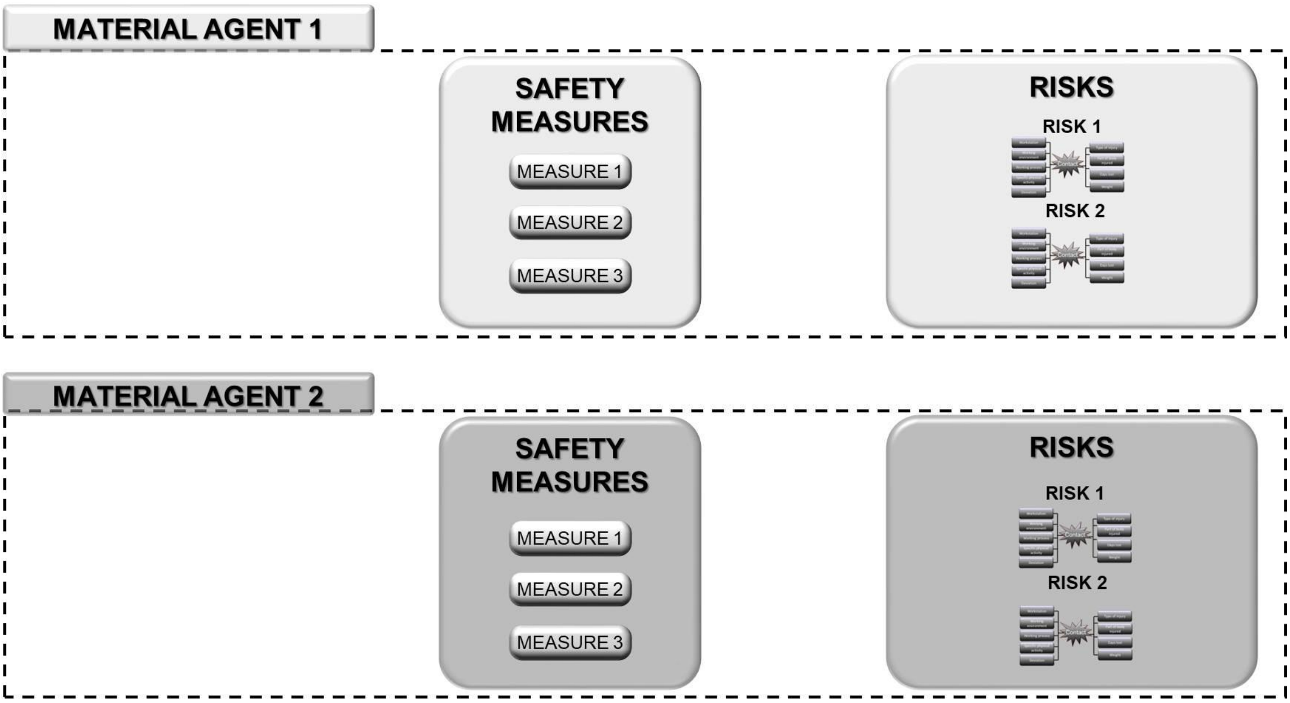

Figure 3. Material agents' modules.

As described in Paragraph 1.2, the amount of data required per enterprise is particularly large. To avoid requirement for enormous data entry that would make the system non-feasible, "data leveraging" was introduced. Since many general policy measures are common for the whole workplace (e.g. no lone working policy), they can only be answered once per workplace and this answer can then be transferred to every relevant material agent's module, (with an option to manually differentiate in exceptional cases). Hence, only a few specific measures need to be answered separately for every material agent. With this "data leveraging" only a tenth of the data logs used by the model needs to be manually entered.

Hence, the web-application consists of a general module for horizontal safety policy measures and individual modules with specific safety measures for each material agent that need to be answered

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when the material agent is selected as being present in the workplace. Identification and compliance-based assessment of risks occurs automatically.

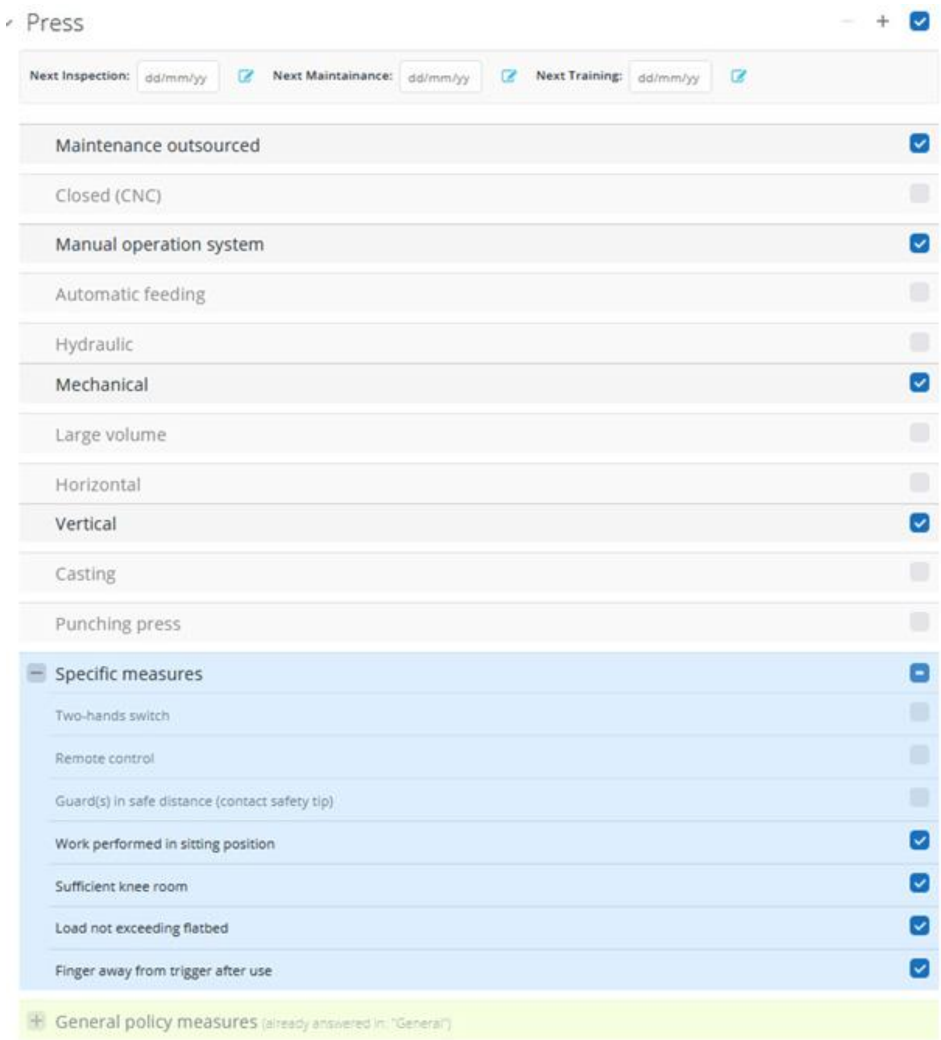

Figure 4. Example of a material agent's input interface.

The web-application can provide a number of reports for compliance and risks in a uniform way, in order to act as leading indicators for safety. Such factors could include enterprise's indicators (total risk, severity or likelihood indicators, as well as distribution of risks), risks' indicators (risk assessment, severity, likelihood and prevalence - i.e. to how many material agents the same risk appears), measures' indicators (prevalence - i.e. to how many material agents the same measure applies, total risk reduction - i.e. the total reduction of risk assessment obtained by taking the measure, in all material agents where it applies) and priority (size of risks where the measure applies).

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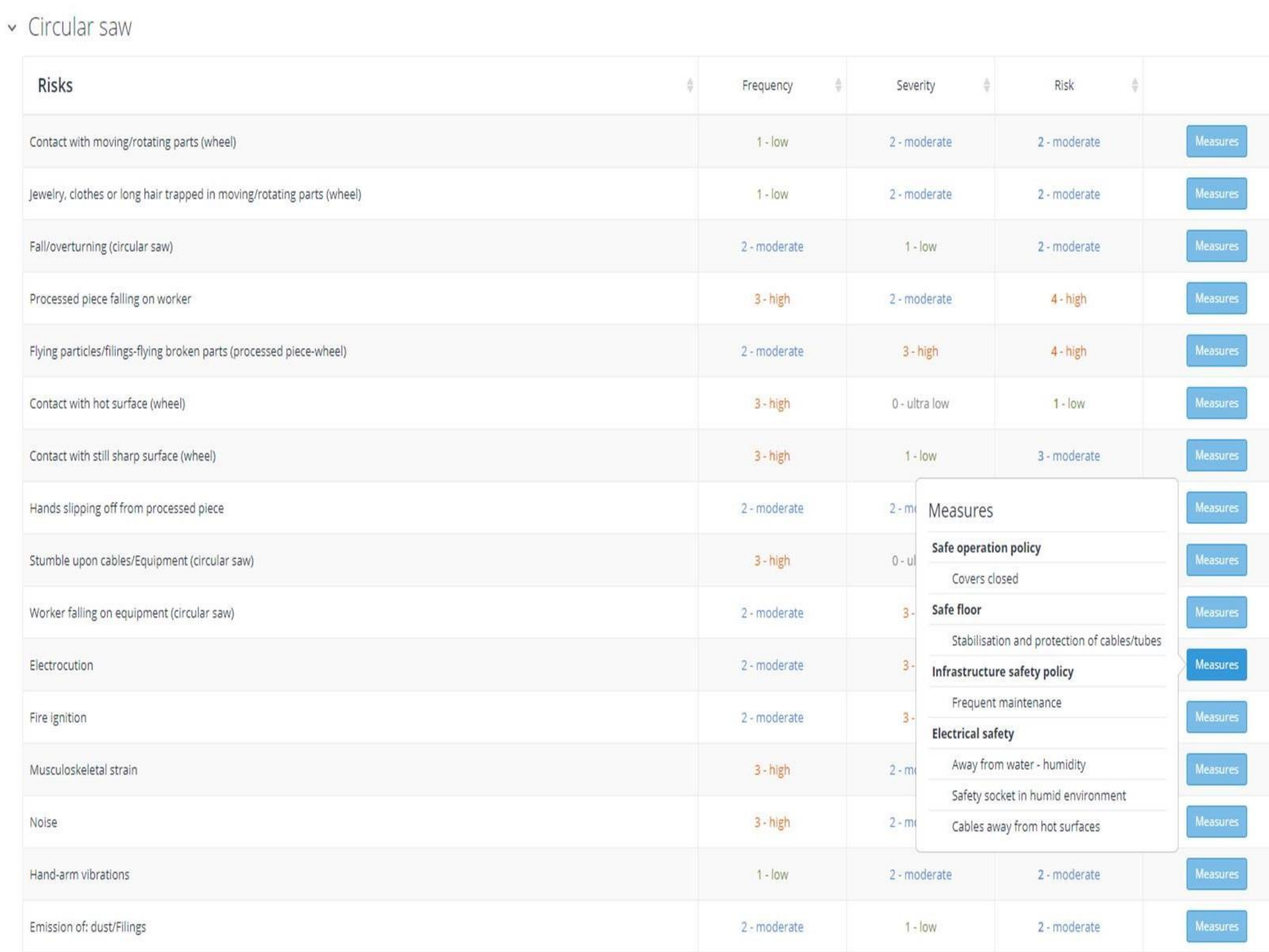

Circular saw

Risks	Frequency	Severity	Risk	
Contact with moving/rotating parts (wheel)	1 - low	2 - moderate	2 - moderate	Measures
Jewelry, clothes or long hair trapped in moving/rotating parts (wheel)	1 - low	2 - moderate	2 - moderate	Measures
Fall/overturning (circular saw)	2 - moderate	1 - low	2 - moderate	Measures
Processed piece falling on worker	3 - high	2 - moderate	4 - high	Measures
Flying particles/filings-flying broken parts (processed piece-wheel)	2 - moderate	3 - high	4 - high	Measures
Contact with hot surface (wheel)	3 - high	0 - ultra low	1 - low	Measures
Contact with still sharp surface (wheel)	3 - high	1 - low	3 - moderate	Measures
Hands slipping off from processed piece	2 - moderate	2 - m		Measures
Stumble upon cables/Equipment (circular saw)	3 - high	0 - ul		Measures
Worker falling on equipment (circular saw)	2 - moderate	3 -		Measures
Electrocution	2 - moderate	3 -		Measures
Fire ignition	2 - moderate	3 -		Measures
Musculoskeletal strain	3 - high	2 - m		Measures
Noise	3 - high	2 - m		Measures
Hand-arm vibrations	1 - low	2 - moderate	2 - moderate	Measures
Emission of: dust/Filings	2 - moderate	1 - low	2 - moderate	Measures

Figure 5. Example of a material agent's risk report.

The application was also developed in order to be used as an interface for automatic and standardized incident reporting to also provide lagging indicators. Having listed all material agents, along with the relevant risks and related measures, the process of incident reporting can be fully guided, standardized and automated. By initiating declaration of an incident, a list of the existing material agents occurs in order to declare where the incident took place; the list of risks associated with the selected material agent then appear, in order to choose which one occurred. Then the missing measures related to this risk, at the time when incident was reported, occur automatically. This operation could provide a common language between analysis of risks and analysis of incidents, which will help improving the system by updating weighing factors based on aggregated incident statistics.

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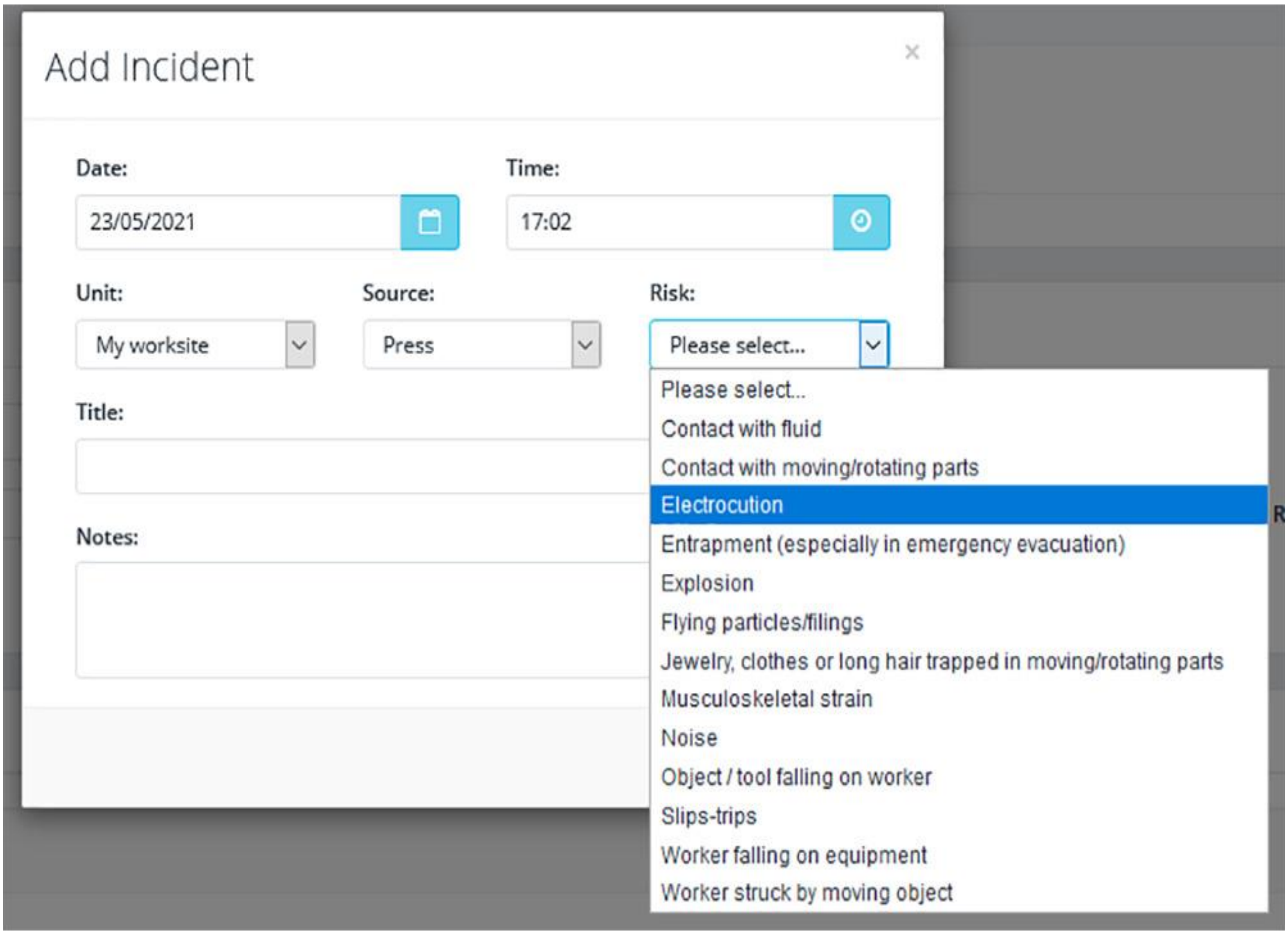

Figure 6. Incident reporting.

The enterprise's interface of the relevant web application is already operable in experimental mode and openly available on line for review and testing (www.riscout.com).

4. DISCUSSION

4.1. Changes in the Governance of the Occupational Risk System

No model or tool can change the system by itself. The application of the proposed approach requires changes in the paradigm of governance of the occupational risk system, as it is not compatible with many features of the current paradigm.

Despite the extended regulation, the whole current system of occupational risk governance is extensively decentralized. The prescriptive "command-and-control" approach to the system led to some kind of mandated partial self-regulation [32]. This approach can be roughly described by Figure 7.

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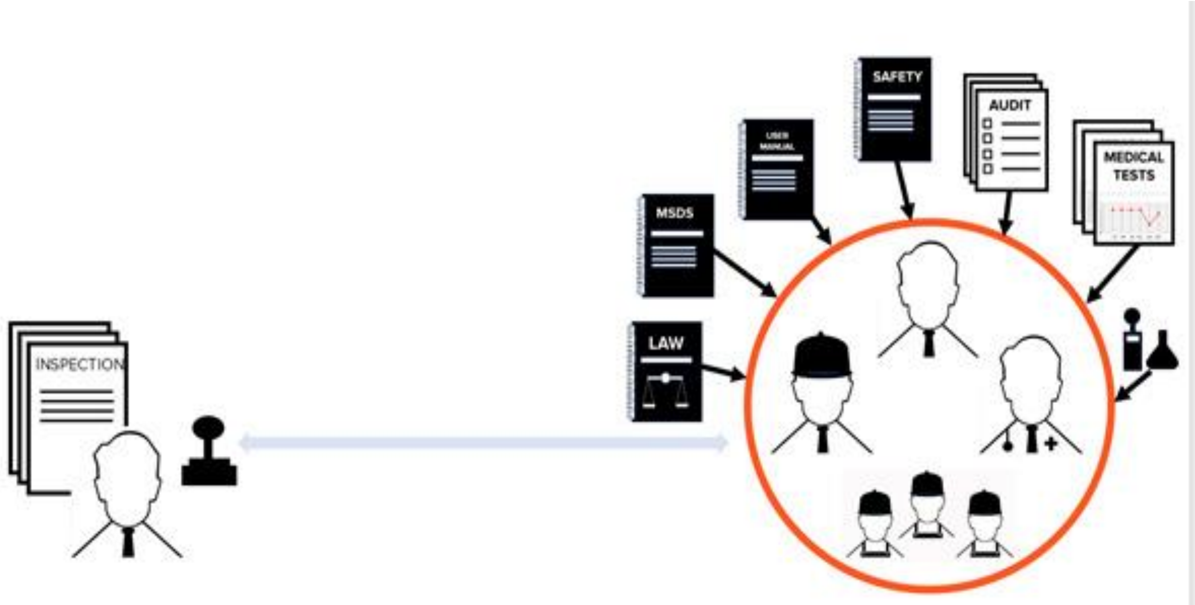

Figure 7. Current approach to governance of occupational risk system.

Enterprise is a bounded, almost autonomous system that has been assigned to translate multiple sources of information (legislation guidelines and measures, user manuals, material safety data sheets, findings of internal audits, environmental factors' sampling, literature, etc.) into certain safety measures. In this partial self-regulation process, some specifications are prescribed (specific measures by legislation, e.g. safety guards), but their relevance and importance is evaluated subjectively and prioritized by enterprises in a non-standardized way; nevertheless, this evaluation does not commit the authorities in their inspections.

Communication with authorities is generally loose and takes place mainly through sporadic on-site inspections. In these occasions, enterprises are still inspected on the basis of their compliance to certain measures of the legislation (e.g. guard around moving machinery parts), which is ultimately law that has been violated. Prioritization of the safety measures and their impact on safety is left to inspector's discretion.

Application of a model that links compliance to safety, like the one developed in this research, requires a close communication with structured exchange of large amounts of data, as described in Paragraph 1.2. This exchange can only be achieved through a central uniform interface between the enterprise and the authorities.

To obtain this interface, all sources of knowledge must be centrally processed and translated into uniformly assessed lists of specified measures, same for all enterprises that do not leave room for subjectivity or vagueness. Figure 8 describes this new proposed approach.

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Figure 8. Proposed approach to governance of the occupational risk system.

Figures 7 and 8 show the required transition from a partial self-regulation to regulated self-reporting. It is evident that in such a transition, compliance control should be replaced by compliance management, where non-compliances will be assessed and managed on the basis of their impact in occupational risk, according to the structure described in previous paragraphs. Priorities for preventive action should be set based on their assessed impact on total risk ("value" of the measure, i.e. number of relevant risks affected, size of relevant risks, weighing of measure in different risks, etc.) rather than simply whether they are prescribed in legislation.

Management of compliance also requires motivation for enterprises to have an open and sincere communication with authorities. Reporting a non-compliance should not lead to direct sanctions that would discourage it. Sanctions should be limited to non-reporting, false reporting, or negligence to comply with priority measures, rather than non-compliance in general. In other words, such an application should not be a calculator of the total non-compliance fine, but a compliance-based risk assessor that would help enterprises and authorities to exchange information and manage compliance.

4.2. Possibilities, Limitations and Requirements

The existence of a pre-defined, certain and complete set of common specifications for compliance, can provide important benefits to enterprises, inspection authorities, insurers and researchers that are described in this Paragraph.

It can only be applied in a horizontal and compulsory basis for enterprises. However, they will also be benefited, as the predefined, common and structured check-lists will ensure equality, objectivity and transparency of inspections. Moreover, having certain and common measures to comply that are defined and known in advance, reduces ambiguity, subjectivity and uncertainty induced by inspector's discretion. Finally, enterprises can have an automatic compliance-based risk assessment with priorities for measures required to be taken at any time, without the intervention of an inspector.

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Inspection authorities are the most important beneficiary of such a system. The system can offer a real-time holistic coverage of safety surveillance without excessive requirements in inspection resources, which is not possible through on-site inspections. Targeted inspections, when required, can be carried out from office saving cost and time (particularly for preparation, commuting and induction). However, the flow and processing of data is done automatically by the system, providing alerts only where inspection action is required.

Dependence on inspectors' expertise (which requires advanced skills in different scientific disciplines, particularly in an era of fast technological pace) is reduced, along with the relevant risk of incoherence or subjectivity. Moreover, based on solid requirements, inspectors can feel more confident against omissions, objections or ambiguity. Their testimony is about existence of certain measures rather than assessment of risk.

The most important benefit of the proposed approach for the authorities is big data, which on one hand can help for a uniform benchmarking and rating of enterprises on leading indicators and, on the other hand can assist analysis for better policies comparing specifications with risk and related incidents, setting the scope for future campaigns.

Generally, the system can help "overcoming the difficulties of correct identification of risk factors and maintaining the availability of experts in different fields in OHS, who will be less and less present on the shop floor" [25].

Providing a common ground of reference between enterprises and authorities (i.e. certain, common and predefined specifications for compliance and rating criteria), it can improve conciliation, as well as the needs of employer's education by inspectors.

The possibility to rate enterprises in a common scale, with common standards and based on leading indicators (rather than on their accident records, as it happens in experience rating) could also be useful for occupational risk insurance schemes to calculate variable insurance premium. Using the same inspection scheme would also help overcoming problems with the duality of inspections, conducted independently by insurance schemes and labor inspection [33]. Research community can also be benefited by having huge amounts of relevant and timely data for analysis.

Being an on-line application, it can be updated and improved continuously following advances in technology and policies, as well as experience (incident analysis in the same platform). It can immediately include new legislation, as well as urgent guidelines for extraordinary cases of workplace risk, like the current Covid-19 crisis, also getting immediate real-time feedback and a direct picture for compliance of enterprises against these guidelines.

The first limitation of this approach that comes to mind is reliability of self-reported data. The risk of misreporting is always there; however, misreporting clear specifications is a discrete and deliberate violation, as no ignorance or lack of skills can be invoked. Sampling on-site inspections combined with sanctions could actually discourage this phenomenon. It has to be mentioned that self-reporting is not a novel approach; it has been traditionally accepted in several functions (e.g. taxation).

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Another limitation is that the assumption that occupational risk is only a function of (already identified and regulated) legislation specifications is only a convention, as further factors could affect occupational risk. However, this assumption is necessary to regulate the system and can be improved with better regulation, although it can never be eliminated.

Finally, another limitation of the current approach is that it is only a first conventional step, as it depends on a manually entered basic dataset that can be a bottleneck in the whole system, both in terms of delayed or inaccurate self-reporting and therefore effort is required to maintain its operation.

Such limitations could be improved in the future with enrichment of the system. Moreover, model uncertainty (e.g. deficiencies in relevance and weighing of measures) can be reduced in a self-learning continuous process based on the collected data and comparison between incidents and assessed risk. In any case, such a central system for massive data exchange is a necessary first step for future development.

Of course, shifting system structure requires a lot of efforts in terms of regulation, training, resource allocation and change of culture. However, these are necessary efforts to keep up with a world depending more and more on data exchange and flexibility.

5. CONCLUSION

Bridging the gap between priorities for compliance and risk minimization and overcoming the deficiencies caused by this gap, requires the exchange of big data between enterprises and the authorities, which is possible nowadays more than ever, due to advantages in technology and mentality of enterprises.

Research presented in this paper started with the development of a conceptual model, linking compliance to legal measures with occupational risks. This model was subsequently integrated in a framework and codified in a web application to demonstrate its applicability and practicality.

Despite any deficiencies in the proposed models and tools, the idea of a central translation of legislation into certain and universally applied measured as an interface for exchange of data between enterprises and the authorities, can serve equality, objectivity, transparency and motivation of enterprises to improve working conditions and reduce occupational risks.

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