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## On the future of safety in the manufacturing industry

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### Abstract

This paper argues that a new paradigm is needed in the manufacturing industry to further substantially advance safety as part of the industry 4.0 concept. The different domains that need to be focused upon are Cluster-thinking and cooperation, High transparency and efficient inspections, Education and training, Security integration, and Safety innovation. Since society has fundamentally changed over the last two decades, revolutionizing safety via these domains is truly needed in the future as part of “industry 4.0” in manufacturing plants.

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*Keywords:* safety; security; manufacturing industry

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### 1. Introduction

It is very difficult to draw conclusions about the increase or decline in the number of accidents in the manufacturing industry over the past decades. Nonetheless, it goes without any doubt that still too many accidents do happen in the industry. Besides major accidents, also many occupational accidents happened in the manufacturing industry since the beginning of the 20th century. Nonetheless, in general, despite lacking aggregated figures, we may assume that, due to safety efforts and safety improvements of different kinds during the past decades, a decreasing accident trend in many companies belonging to the manufacturing industry, is present. However, accidents do keep happening. Moreover, if we only look at occupational accidents, we observe in industrial practice that in many cases there seems to be a certain minimum threshold of a number of such accidents, below which it is very hard to reach for companies. Hence, the ‘business-as-usual’ approach for dealing with safety in the manufacturing industry seems to be insufficient to truly advance safety. Therefore, a paradigm shift is needed.

Such a paradigm shift should actually provide an answer to our changing society with its own specific needs and societal expectations, including, for instance, more transparency and the inclusion of economic, moral and ethical aspects in risk assessments. In this regard, the increasing trend of new security challenges such as terrorist attacks not only throughout the world but also to the manufacturing industry should also not be overlooked. Some other observations are that the manufacturing industry does not seem to adequately - and to its full potential - have learned from past accidents since still a majority of approaches toward safety are reactive and not proactive, and manufacturing companies in industrial parks are still dealing with safety issues too individually, that is, from a “safety-islands” perspective instead of a “safety industrial parks” viewpoint.

Some questions can be formulated that may feed the paradigm shift. How to integrate different types of risks (e.g., domino effects, land-use-planning, natech accidents, security risks, etc.) when making risk decisions? How to deal with horror scenarios (e.g. terrorism) from a sustainable viewpoint? How to consider moral aspects in decision-making? How to develop usable and inclusive dynamic risk assessment techniques, using big data and real-time monitoring? How to advance academic knowledge regarding physical- and cyber security? How to truly advance collaboration and cluster-thinking? How to innovate safety within the manufacturing industry in a sustainable way, whereby the energy transition, land-use planning, safety behavior, etc. are all considered? How to initiate and advance strategic proactive and reactive collaboration in industrial parks? How to increase people knowledge about safety, or e.g., how to encourage students to pursue majors in chemical process safety and security?

## **2. Safety trends in the manufacturing industry**

The number of safety-related tasks in any organization is huge, so are the responsibilities accompanying the decisions and choices that have to be made. Well-known (technical) aspects of safety in companies, that is, hazard identification, risk analysis and risk assessment, are only one part of the larger domain of dealing with risks by company safety managers. Other elements are, for example, safety training and education, training-on-the-job, management by walking around, emergency response and planning, business continuity planning, ethical aspects of safety, reliability engineering, learning from incidents, risk communication, risk perception, psycho-social aspects of risk, economic aspects of safety, risk governance, and many more. Meyer and Reniers [1] define operational risk management as “the systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, evaluating, treating and monitoring risks”. From a rather very technical approach, safety management has widened towards an approach encompassing all these other domains, to a lesser or higher extent.

Furthermore, the scientific background and the disciplines tackling the different domains and items from the risk management set are ever more diverse. Safety- and risk management is no longer the exclusive terrain of engineers, physicians, and safety scientists; in fact, sciences such as psychology, sociology, pure mathematics, chemistry and physics, philosophy, economists, communication, business and management, criminology, and law are also involved in safety improvement these days.

We discern three areas to explain the safety improvements that have taken place the past decades in the industry (including the manufacturing industry): the proactive phase (pre-incident), the incident phase, and the reactive phase (post-incident). In the proactive phase, a variety of trends can be observed and discussed. The first trend is that there is ever more cooperation between companies, mainly on an operational level and mostly concerning reactive issues such as accident investigations and evacuation exercises. More collaboration among companies and academia and authorities can also be seen. The second trend concerns making risk assessments less static and more dynamic. Dynamic risk analyses include advanced mathematical-based techniques being developed in the academic world including Markov chains, Event sequence diagrams, Petri-nets, and Bayesian Networks. In the same line of thought, big data and the Internet of Things have increasingly started to be incorporated, where and when possible, in such dynamic risk assessments. Furthermore, operational economics including cost-benefit analysis and cost-effectiveness analysis are improved and employed with an increasing trend. Some specialized topics are also explored, introduced and developed in chemical corporations, such as security risk analyses, performance management science, mental models and moral or ethical principles for calculating risks. The attention for systemic risks, whereby one looks at the whole system on top of (analytically) looking at its parts, leads to the taking of safety barriers at a systemic level. An example is that one looks at a whole chemical plant at once instead of merely at its installations or installation parts. Besides, a variety of scientific disciplines is used to come up with trans-disciplinary solutions. All kinds of

safety apps can further be expected to lead to optimized communication and perhaps much better safety decision-making. Innovation with respect to the so-called ‘safety-culture’, using, for example, High Reliability Organization principles or newly developed leadership styles such as Total Respect Management [2] are also being elaborated.

In the incident phase, also some trends can be observed. Real-time data and big data, as well as all progress in communication devices and possibilities have led to better and more objective risk assessments and decisions. Large-scale simulation exercises of disasters are made more real while serious games to exercise incident-phase decisions and tasks are elaborated. Collaboration between different actors in the incident phase is also improved.

During the aftermath of an accident, an important trend of improvement concerns better collaboration among rescue workers, fire-fighters, industrial practitioners, medical services, logistics services, communication experts, and academics. But also the use of innovative technology (e.g., drones), certain human aspects (e.g. trauma-psychological aspects), and organizational structures to deal with problems in a post-incident phase, are improvements that cannot be disregarded.

### **3. A new safety paradigm is needed**

The previous section provided the evolutionary safety trends which can be discerned in current academic research and industrial practice. However, these trends represent thinking ‘within the box’, and are usually “more of the same concept/approach” or, at best, incremental improvements and optimization of existing technology, management practices, organizational arrangements, and human factors. To truly advance safety within the manufacturing industry, as part of the industry 4.0 concept, “out of the box” thinking is needed, and a true revolution is necessary. But what should such a revolution contain, and who could realize it?

Revolutions start with radically new ideas. These new ideas are formed via mental models, the willingness to change things, and the understanding that changing things will lead to an improved situation, which in the case of manufacturing plants, will result in their profitability and license-to-operate. Such should be the case with a new safety paradigm in the manufacturing industry. As also indicated by [3] for the chemical industry, this new safety paradigm for the manufacturing industry should consist of five focus domains. The new safety paradigm can be represented by the acronym ‘CHESS’, summarizing 5 very important fields where revolutionary progress is needed: (i) Cluster-thinking and intensified cooperation; (ii) High transparency and efficient inspection; (iii) Education, training and learning; (iv) Security integration; and (v) Safety innovation and dynamic risk assessments.

At first sight, these fields represent well-known recipes for improving safety in any industry, and they are nothing new. However, one should realize that the combination of these domains could indeed lead to a third safety revolution in the chemical industry if they would be addressed in radical innovative ways. The required innovation can be exemplified by a number of concrete ideas, which can only be realized if current mentality of practitioners, academics and authorities changes.

#### *3.1. Cluster thinking and intensified collaboration*

For the first revolutionary field, cluster-thinking and collaboration intensification, some thorough research has already been done [4]. Cooperation on a proactive and strategic level such as joint emergency management strategies and decision making tools, besides reactive and operational level cooperation such as joint evacuation drills, should be strived for. Some industrial parks already work together to strategically improve horizontal logistics and the use of energy (or utilities in general), or even concerning environmental issues (e.g. waste streams); however, they usually fail to collaborate much more intensively with respect to proactively and strategically enhancing safety.

The following concrete novel measures are for example to establish a multi-plant council or a cluster council, to establish proactive strategic cooperation and improvement by setting up a ‘cluster safety funding’ budget; to use ‘flying risk assessment’ teams and ‘flying internal audit’ teams in clusters; to establish a cluster emergency planning matrix; to take various forms of risks such as domino effects (escalating accidents) and natech accidents into account in risk assessments; to establish a cluster safety management system upgrade approach; to establish a cluster safety culture on top of the individual plant safety cultures.

### 3.2. *High transparency and efficient inspection*

The second revolutionary field, high transparency and more efficient inspection, can find useful inspiration in the aviation sector. In this sector, a mature system of procedures and agreements is worked out to deal with the reporting of all incidents and near-misses in order to learn as much as possible in a ‘just culture’ setting.

The following innovative approaches can be introduced and elaborated in the manufacturing industry, wherever worldwide: to establish a national database to report all types of incidents and accidents by manufacturing companies; to establish a ‘just culture’ in manufacturing plants and industrial parks containing manufacturing companies; to establish a dissemination system where companies and authorities/inspection teams can learn from all incidents happening within the industry; to establish an understanding between cluster safety council members and inspection services to make inspections much more efficient; and to use drones to continuously gather data from around the cluster for safety purposes.

### 3.3. *Education, training and learning*

The third revolutionary field, dealing with safety education, safety learning and safety training, also deserves dedicated attention. One not only needs to learn from all kinds of near misses and incidents, but also from safety models, theories and knowledge in general. Here lies also a task for society: there should be courses on ‘dealing with risk and uncertainty’, or ‘operational safety’, starting from primary school education. If people get familiar with safety from very early ages, they can learn much more in higher education. Moreover, it can be expected that the much more thorough safety knowledge of all people through regular education will be used in life and business to make better decisions and reduce losses, both on private- and public working levels.

In this regard, some interesting innovations may be suggested. Knowledge management systems should for instance best be present in every manufacturing plant; There should be training sessions where plant safety managers and safety inspection services are jointly present; Safety learning should be supported by adequate/validated/scientifically investigated performance management science; a course such as ‘basic knowledge of valuing and prioritizing safety issues’ should be taught to children in primary schools; ‘Risk management and risk-based decision making’ should be taught at high schools and universities, either as a separate course, or within existing courses; ‘Process safety’ (and inherent safety) should be taught to all chemists, chemical engineers and industrial engineers, and be considered as essential in the educational program.

### 3.4. *Security integration*

The fourth revolutionary field, security integration, mainly concerns more effective counter-terrorism security practices in the manufacturing industry. At present, security efforts in manufacturing plants are aimed at low-impact high-frequency security risks, that is, against burglars and sabotage, or, at best, against would-be terrorists. However, an adequate upgrade is needed towards anti-terrorist security measures. But more in general, security should be treated in an integrated way with safety by company safety management. Safety and security both concern the avoidance and mitigation of losses of different origins (safety looks at possible unintentionally caused losses, while security is about tackling deliberately caused losses).

Some innovative ways to improve this fourth domain are to carry out threat assessments, security vulnerability assessments or, in general, security risk assessments in all manufacturing plants/clusters (alongside safety risk assessments, and in an integrated manner); to use a cluster view to take counter-terrorism measures, besides a plant view; to make a priority of hazmat transportation security (transportation risk assessments and measures based on these assessments, secure lanes, secure emplacements, etc.) within a chemical industrial area; to establish cluster security teams; to develop a security incident database; to establish security inspections for manufacturing plants and –industrial parks (alongside safety inspections), and to take counter-terrorism measures seriously, preferably design-based by scientific studies.

### 3.5. Safety innovations and dynamic risk assessments

The fifth revolutionary field, safety innovation and dynamic risk assessments, builds on the evolutionary trends of Section 2 of this paper and is therefore the most evident field to work on. This field requires the least change in the mentality of practitioners, academics and authorities. Nonetheless, due to the fact that it is the most demanding field from a technological perspective, it is the highest hanging fruit.

Some innovations that, if applied together, would make the evolutionary trends a true revolutionary field, are mentioned hereafter: use big data and the Internet of Things to innovate risk knowledge and safety decision-making within manufacturing plants and industrial parks; use dynamic risk assessment techniques (make large investments in their development and on-site application) to advance real-time knowledge and decision-making; invest in research for performance management science and safety/security performance indicators (should be proactive mainly) to see which indicators work and which don't (this requires large-scale longitudinal studies); develop serious games for a large variety of safety and security major accident scenarios and terrorist attack scenarios and employ them for learning and exercising; develop science with respect to leadership and its required mental models of employees, and the impact on safety; develop alternative risk assessment techniques whereby both ethical/moral principles and economic information are considered.

## 4. Conclusions

Achieving a paradigm shift for safety in the manufacturing industry, as part of the industry 4.0 concept, will be very challenging and ambitious for all stakeholders, yet it is achievable in industrial practice and it can in the long term be very rewarding for safety and company profitability. It would undoubtedly lead to an improved acceptability and acceptance of risks in manufacturing plants as perceived by current society that is ever more risk averse and demands for more transparency and more communication. A strong competitive advantage for industrial parks that would act as first-movers, could probably be created, providing opportunities for large-scale investments in their industrial activities.

The new safety paradigm can be achieved via five revolutionary fields denoted by acronym 'CHESS': Cluster-thinking and cooperation, High transparency and efficient inspections, Education, Security integration, and Safety innovation. These revolutionary fields can truly and in a sustainable way change the safety landscape within the manufacturing industry.

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