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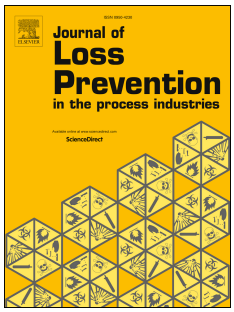

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What About Nudges in the Process Industry?

Exploring a new safety management tool

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Highlights
- Safety nudges are studied as a new approach for safety management
- 9 existing and well proven nudge types are proposed to be used by safety management in the process industry
- An extensive list of nudges and references is provided in the paper
- A development, implementation and evaluation approach for safety nudges in the process industry is suggested

Abstract

Since the nineteen sixties, after the successive introductions of safety equipment, standards, inherently safe process designs, sophisticated safety management systems and a suite of process safety indicators, all that remains to be slayed in 'safe work' would seem to be the person centered part. The presence of major hazard and risk control via well-established safety management systems in the process industry offers a unique opportunity to add safety via nudges. Psychology and behavioural economics have already entered the safety science realm. Behaviour-based safety emerged in the early nineteen eighties and is in need of an upgrade. Where conscious behaviour according to unwritten cultural rules and written instructions are not enough for safety, additional manipulation of unconsciously made choices might be used. This principle, which is called a 'nudge' towards desirable behaviour, is already being applied in e.g. traffic control, public space, politics, energy saving, health care and trade practice. Nudging may have uncertainties about its feasibility and magnitude of its effects, might be developed specifically for certain application areas, might raise ethical concerns and – hence – requires investigation of its application boundaries. The potential of improving safety this way resides in the human error domain and may not only reduce hitherto unaffected unsafe behaviour but also increase rule compliance on legislation, procedures and codes of conduct. This article explores 'safety nudges' and proposes a new safety management tool for influencing behaviour of workers in safety controlled environments in the process industry. Based on currently available evidence, a set of 9 nudge types and an implementation approach are proposed.

Keywords:
Process industry, chemical industry, nudge, behavioural economics, behaviour-based safety

1.Introduction

After technology, standards and compliance were introduced since the nineteen fifties in order to improve safety in industry, the safety management systems from the nineteen seventies focused on risk assessment and mitigation. Each of these first and second ways to improve safety, led to successive overall drops in incident rates (Hudson, 2007). After achieving major reductions of occupational accident rates in industry, transport and health care over the last 100 years (Weeks, 1991; CDC, 1999), by their successive introduction it became clear that technology and safety management systems alone could not ensure safety and that a a third way, a concerted 'group effort' and '-culture' were needed (Cox & Flin, 1998; Langford, 2000). Psychology entered the realm of occupational safety via training of personal skills, behaviour modification and team development (Sonntag, 2001). Current industrial safety practice is focused on 'safety culture' and its non-standardized metrics (Thomas, 2012).

This third way of improvement started with the emergence of behaviour-based safety in the early eighties, matured in the nineties and got established shortly after the year 2000 when it was named the the safety culture paradigm (Hudson, 2007), as shown in Figure 1. Accident causality points at unsafe acts and organisational factors as the last problem to solve (Amalberti, 2001; Amalberti, 2002; Reason, 2009; Gibb et al., 2006; Hopkins, 2006; Anderson, 2005; Knegtering et al., 2009). Although at the same time slowly emerging concepts like '*prevention through design*' might eliminate hazards in the construction industry, the elimination of unsafe behaviour would make most occupational accidents disappear. Therefore, safe behaviour ought to get more attention (Bhattacharjee et al., 2011; Talabi et al., 2015). Within this kind of 'safety culture' thinking, any further reduction of harm to workers exposed to dangerous situations would need to involve understanding and control of safety (critical) behaviour (Krause et al., 2001).

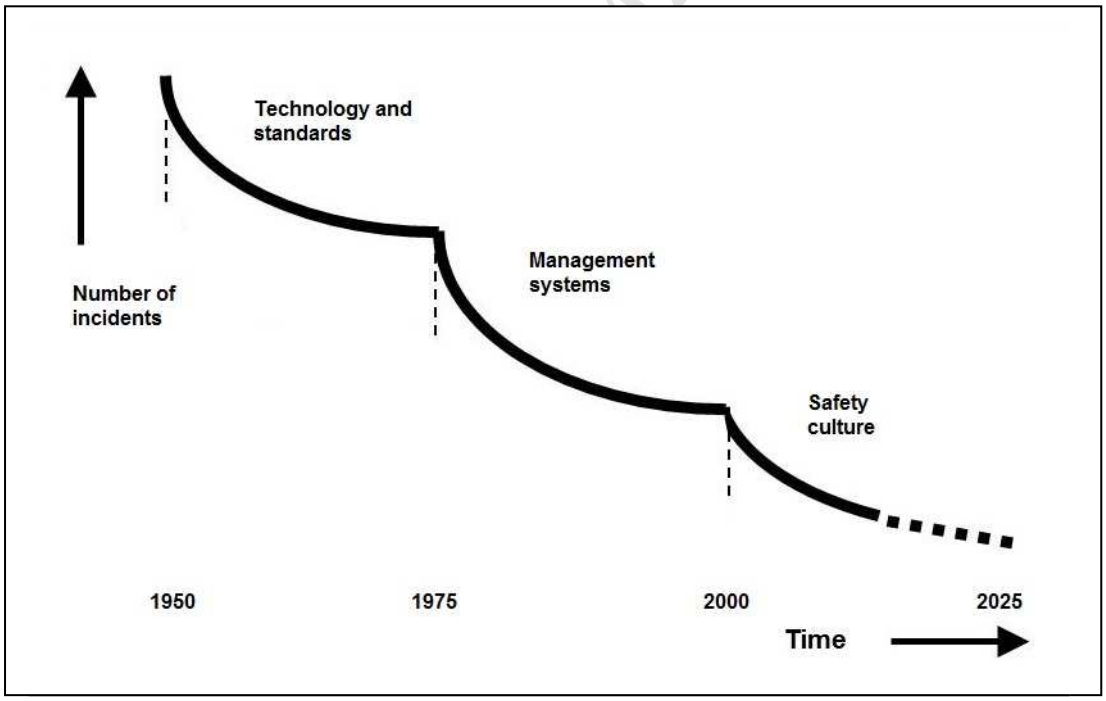


Figure 1 Industrial incident rates over time (after Hudson, 2007)

Current insights show however that people are not always following logic in their behaviour (Kahneman, 2011). Hence, strictly rational utilitarian models are not enough to achieve such understanding and control of safety critical behaviour in situations with safety risks. Some form of paternalistic behavioural guidance is required (Thaler & Sunstein, 2008). Different levels of

paternalism ranging from 'soft and weak' to 'true and strong' exist. The 'weak' form is influencing the individual's preference in a situation of compromised voluntariness or autonomy, e.g. cognitive disability, ignorance, false beliefs or immaturity. The 'strong' or 'hard' form would be to interfere in the preferences based on their contents, possibly not in the individual's interests, without compromised autonomy or rationality, in situations with e.g. drug- or alcohol abuse (Faden & Shebaya, 2015). A justified – weak or strong – form of paternalism offers government an additional means of guidance next to legislation. In practice this leads to 'influence strategies' to point out but not enforce peoples' choices in the 'good' direction as perceived by themselves. These strategies result in implementation via gentle behavioural pushes, referred to as 'nudges' by Thaler & Sunstein (2008), and in actions, based on convincing and free will instead of rules and instructions (Oullier et al., 2010).

The term 'nudge' was coined by Richard Thaler and Cass Sunstein in behavioural economics. They were looking at possibilities to influence kids to make healthier choices in school cafeteria's in Chicago around 2006. They defined it as: "*A nudge, as we will use the term, is any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid. Nudges are not mandates. Putting fruit at eye level counts as a nudge. Banning junk food does not.*" (Thaler & Sunstein, 2008, p.6). Nudges can be applied also for other purposes, e.g. to improve energy saving (See: www.nudge.nl).

Using behavioural biases to improve the wellbeing of people via 'nudges' is being proposed in the 'libertarian paternalism' concept. The individual is considered as free to choose differently than the 'nudge' intent and this is therefore classified as a 'weak' form of paternalism (Thaler & Sunstein, 2008; Hansen & Jespersen, 2013). The 'libertarian' aspect is being criticized however, since influencing automatic behaviour does not reach the level of conscious thinking required for a free decision (Vallgarda, 2012). With this in mind, a safeguard to ensure 'nudges' are in the interest of the general public is being proposed, usually referred to as the *Rawls's Public Publicity Principle* (Thaler & Sunstein, 2008; Rawls, 1971).

Instrumental use of 'nudges' was implemented in a variety of areas such as health care (Ploug et al., 2012), finance (Thaler et al., 2004), traffic control (Groot Mesken et al., 2014; Oullier et al., 2010; Avineri et al., 2014), sustainability in market development (O'Rourke, 2005), energy saving (Hallcot et al., 2010), nutrition (Reisch et al., 2013; OECD, 2010) and retail (Goldstein et al., 2008; Kroese et al., 2015).

A growing quantity of academic literature is being produced about suspected possibilities to influence people using 'nudges' in all sorts of situations, about the intricacies of choice architecture, about their effectiveness and about ethical concerns related e.g. to unconscious behaviour change without consent. Some strategies to influence behaviour through redirection of financial benefit or prohibition have been called 'nudges' but in fact aren't fitting in the definition presented by Thaler & Sunstein (2008). Several types of 'nudges' appear to be susceptible to cultural- and situational differences, making predictions of their effect uncertain. Even well designed life-style interventions show a wide variety of success levels. 'Fuzzy' nudges may, though well intended, achieve less than predicted or even the opposite of the intended effect (Neal et al., 2004; Selinger & Whyte, 2011; Bovens, 2010; Tengland, 2012; Van der Heijden et al., 2015; Zohar et al., 2005).

Hence, in response to criticism on libertarian paternalism as such, on doubts regarding the effectiveness of a nudge, and considering the ongoing debate on ethical concerns, the limitations of the 'nudge' approach need careful assessment (Blumenthal-Barby et al., 2012; Blumenthal-Barby et al., 2015; Hansen & Jespersen, 2013; Codagnone et al., 2014).

2.Paradigm

In this article we focus on health and safety at work and the possibilities to improve those with 'nudges'. In many areas in society, in organisations and even by individuals, 'nudges' are used to

achieve their goals. These 'nudges' may originate from many different areas. Schoolkids may be influenced to choose healthier food during lunch, car drivers may reduce speed at risky crossings, insurance brokers may offer safer choices in such a way that they are selected first and hotel guests may be persuaded to use their towel twice for environmental protection reasons. All these are examples of nudges currently being applied in daily practice.

Safety management could perhaps benefit from experiences in all these areas. Nudges might e.g. be used to help to protect workers in the presence of a known hazard to use suitable safety provisions. So, could such 'safety nudges' be introduced into safety culture? Some scientists claim that, like the Behaviour Based Safety concept, 'nudges' are not suitable as a solution for all safety issues but are merely a part of a general safety management system (Talabi et al., 2015; Talabi & Gibb, 2015).

The common setting in many reported cases is a government or an organisation 'nudging' the behaviour of individuals in either an organisation or in the general public. This way the government regulator might nudge companies to act 'better' on things like sustainability, environmental care, health and safety. Companies may nudge their customers towards more satisfaction and more profit at the same time. An important tool for companies is setting the right '*defaults*' in the decision tree (Goldstein et al., 2008).

All this implies that any organisation might also nudge its personnel to behave 'better' in a variety of ways. The wide range of successful 'nudge' examples in literature so far seems to suggest the presence of a possibly large but not yet utilised potential for safety management. It would add to the concepts of Safety Culture and of Behaviour Based Safety, of which the latter seems in need of a leap forward for quite a while now. One of the possibilities to do that is to make '*safety systems that enable safe behaviour*' (Krause et al., 2001).

We contend that the future development of the safety culture paradigm is likely to absorb findings from research on social marketing, behavioural economics, motivation, influencing and decision-making. This suspected potential would need to address the 'person centered' problem field where other preventive methods are not available (Reason 1990; Talabi et al., 2015; Dekker, 2001; Holden, 2009).

DeJoy (2005) regards change in culture and change in behaviour as two complementary means to improve workplace safety. Hopkins (2011) argues that safety procedures and safety awareness are not mutually exclusive but mutually dependent. Blindly following the rules can even be unsafe without the awareness and the detection of e.g. flaws in written instructions. On the other hand, lack of rule compliance has its own adverse effects on safety. If people are rewarded, their behaviour is more likely to be repeated. Making it a habit and adapting the work environment to enforce the new habit leads to behaviour change (Lally et al., 2013; Brann, 2014*). Any lasting 'nudge' related activity therefore not only belongs to safety culture but needs to be integrated with safety management systems.

3.Problem definition and research question

Any proposed use of 'nudges' should not cause a conflict with compulsory and regulated safety activities. The 'nudge' concept cannot replace legislation and procedures since that would imply workers in the presence of hazard to be free to either comply to the prescribed choice or not, and bring themselves and others in harm's way. The 'nudge' concept could be used firstly to improve behaviour during voluntary, unregulated actions and secondly, to improve rule compliance. The presence of major hazard and risk control via well-established safety management systems in the process industry offers a unique opportunity to explore the addition of safety via nudges.

The – key – research question therefore is:

> *In what way could safety management in the process industry 'nudge' workers towards safer behaviour in a safety controlled environment?*

4.Research methodology

4.1 Research design

We conducted an explorative study. This was necessary since not even a 'nudges' inventory was available as a 'backbone' at the start of the study. The term 'nudge' has been introduced in 2008 and many relevant information sources do not (yet) mention this word. The scientific field around 'nudges' could currently be described as 'emerging' at best. We feel this would make a systematic literature review not appropriate at this time.

Scientific literature presents a plethora of nudge concepts that could all have application potential in the health and safety domain in the process industry. Whether they could actually be modified for use in reducing hitherto unaffected unsafe behaviour by workers, in increasing rule compliance, in identified areas for safety improvement and in other areas of concern in safety practice, depends on two aspects:

1-where the ethical boundaries for nudge application are

Assessing where ethical boundaries are requires looking closer at what a nudge is designed to do. Is it changing conscious choice or is it manipulating unconscious behaviour? Is it to the benefit of the people being influenced ? We propose a classification for nudges to find the answers to these questions.

2-which practical possibilities exist to adapt existing nudges and develop new nudges in a specific application area.

Some nudges may be suitable for the process industry, some may be not. This requires a number of sequential steps to be followed in this study:

-Finding out more about nudges and understand how they work

-Propose a classification of nudge types

-Gather proper search terms

-Make an inventory of nudge types starting from mainstream nudges already identified as having potential for the process industry, for safety in other areas such as traffic and so on, searching in successively widening circles around those until no further nudge types are found.

-Assess the most frequently used nudges and propose a nudges tool set, intended for use in safety practice in the process industry

-Identification of areas for safety improvement in the process industry.

-Creating a useful theoretical framework for development of safety nudges.

-Investigation of the usability of nudge application possibilities in these areas.

-Establish simple criteria from safety practice to determine whether a specific type of nudge qualifies for use in a specific safety improvement area.

-Construct a theoretical framework in order to derive guidance for the development of process safety nudges.

-Review the quality of sources found

-Build a nudge examples library

-Establish guidance for nudge development with testing and evaluation of their effect. To this end a step-by-step implementation approach is derived from practice information found in literature.

4.2 Literature search method

We used 'health and safety', 'behaviour' and 'nudge' to find sources that could lead us towards usable general information sources. Then we expanded the search using key terms found in those general sources. Several of these keywords did not result in any relevant sources, others did. We then composed a sub-set of search terms for further search. With the sub-set of terms, we conducted an explorative internet search (Google Scholar, Scopus, Pubmed), using the terms both individually and in a variety of combinations. This resulted in a series of 'nudge' related sources. We

then extended our search via references listings in those sources to find more sources relevant to the subject.

As we were searching it turned out that information sources for some of the 'nudges' were not all available on scientific level. This study therefore explores both scientific and 'grey' literature about 'nudges' for potential introduction in the process industry (Wessels, 1997).

4.3 Inclusion, exclusion and quality

Scientific literature was searched in English language. We included peer-reviewed scientific articles in journals and scientific books. Quality for so called 'grey' literature sources was ensured by limiting them to of publications from governmental institutions and organisations engaged in nudge development and implementation.

4.4 Analysis

All the identified sources were reviewed in order to find the following types of information:

-Information about how 'nudges' work and about their classification

This information is used to make a nudge inventory.

-Example descriptions of 'nudges' used in practice in a variety of areas

A limited analysis, just roughly exploring their usage frequency, was performed on nudges identified in an inventory. This concerns frequency counting per identified nudge description. In several cases where the same nudge application is described in several references we counted this as a single nudge description. All references in this study were screened for nudge descriptions. Nudge frequency percentage calculations are based on the total number of nudge descriptions found this way. This information is used to create a proposed set of nudges for application in the process industry.

-Theoretical framework for 'nudge' development

This information is used to construct a reference model for the nudge implementation process.

-Guidance on development of a 'nudge' toolset for use in practice in the process industry.

This information is used to compose a step-by step implementation nudge approach for the process industry.

5.Results

5.1 Understanding how nudges work

People are not strictly rational beings. They choose food closer at hand rather than healthier food. They slow down when the distances between stripes on the road are getting smaller. People avoid making choices, so they go for the the 'default' option more often than a rational being would do. Hence, human behaviour can be influenced by seemingly unimportant circumstances. This is where a gentle push, a nudge, can make a difference. A nudge influences how people behave or decide. In order to gain understanding of how nudges work we briefly explore how people think, behave and choose.

People think in two different ways. Thinking is fast and automatic when responding to immediate threats, or catch an unexpected basket-ball thrown at them. Thinking is slow and self-aware when reflecting on the choice between taking the car or the train to go to work, or when figuring out the time to leave. People don't always think in a logical way. They guess, go easy with what is available and assume things work similarly to things they know, just to avoid reflective thinking (Thaler & Sunstein, 2008; Kahneman, 2011). What people do is often about rules of thumb (heuristics) and their flaws (biases) (Tversky & Kahneman, 1974).

Insights about the asymmetry of emotions people feel between loss and gain originate from the seventies. They are of key importance for the understanding of human biases and their effects on decisions and behaviour (Tversky & Kahneman, 1974; Kahneman & Tversky, 1979).

Keil et al. (2007) identify two main bias types that affect problem recognition and decision making: selective perception and illusion of control.
In health care, cognitive bias is considered as a danger to patients that needs to be controlled by health professionals. The work of Croskerry et al. (2013A; 2013B) describes how to take up 'debiasing' as a preventive measure against diagnostic error.
Ly et al. (2013) and Bellamy et al. (2015) point at cognitive bias in unconscious human behaviour, such as: 'confirmation' and 'availability' bias, both meaning that individuals can be focusing on one's own beliefs or ideas to be confirmed when looking around rather than checking for something that confirms the opposite (Tversky & Kahneman, 1974; Kahneman et al., 1982; Kahneman, 2011; Pohl, 2012).
Samuelson and Zeckhauser (1988) describe the 'status quo'-bias, indicating that people adhere to a previously made choice even when a better choice is available.
Such biases have potential for application in safety nudges for the process industry since workers face decisions in situations where perception and control are important for safety (Reniers et al., 2014).

5.2 Classification of 'nudges'

In order to assess the effect of 'nudges' on human behaviour it is important to acknowledge the theory of the dual process, highlighting the two ways the human brain works: 'system 1' is fast and automatic, while 'system 2' is slow and reflective (Kahneman, 2011). Two groups of nudges can therefore be identified (Thaler & Sunstein, 2008):

-group 1 influences automatic, i.e., non- conscious, system 1 behaviour,
-group 2 influences choice as a result of conscious action in system 2 behaviour.

Examples of group 1 nudges are the smaller plate at the food counter in a restaurant, leading to less caloric intake, and narrowing lanes on the road leading to reduction of vehicle speed. Group 2 nudge examples are the seat-belt alarm and asking if a guest in a restaurant would prefer salad rather than chips with their burger.
In practice nudges have a 'dark' side: a person can be 'nudged' without knowing it and that opens the gates for abuse and manipulation. People must be protected from such undesirable effects on behaviour and choice. The definition as proposed by Thaler & Sunstein (2008) and based on a "gentle push" and the assumption about actions being based on free will (Oullier et al., 2010), therefore needs to be extended to cover this area.
In both groups a nudge can be either 'transparent' or 'non-transparent' from the point of view of a nudged person. In other words: a 'nudge' that is noticeable by the person is considered to be transparent. This might be in hindsight though and therefore still may have ethical implications. Group and transparency parameters allow simple classification of nudges in the square in table 1, showing four application zones A, B, C and D. The distinction between transparent and non-transparent 'nudging' leads to a potential different level of acceptability and to different limitations and safeguards per 'nudge' application zone (Hansen & Jespersen, 2013).
This simple classification is used in this study to generate warnings with nudges requiring a check on ethical aspects. Rawl's Public Publicity principle (Rawls, 1971) states that a safeguard must be present to ensure interventions are in the interest of the general public. This would apply in principle to all zones A, B, C and D. In zone C there is little need for safeguarding however.
Table 1 might be used to discuss ethical implications for nudges. For instance, one may contend that nudges in the process industry in the zone A and C application zones have no ethical concerns whatsoever and that zone D nudges, if aimed at compliance with legislation, are justified means for safety improvement. However, some nudges in the zone B application zone might raise ethical issues and might thus need dedicated attention.
The classification of nudges has also been explored in more depth and along different lines of thinking. Haug (2014) looks at ethical nudging and consumer goods and proposes a distinction: along the line of decisiveness.

Table 1 Nudge application zones

Action Behaviour	**Transparent** **Visible**	**Non-transparent** **Invisible**
Group 1 Automatic : Uncontrolled Effortless Associative Fast Unconscious Skilled	*influencing behaviour* Zone A -Safeguard Examples: -make traffic lanes appear narrower to reduce vehicle speed -Play music when boarding an aircraft to calm down passengers	*manipulation of behaviour* Zone B -Safeguard -Paternalistic intervention -Responsibilities with policy makers and choice architects Examples: -Fruit and vegetables at the front of the food counter to get healthier food choice -Use citrus odor to make people behave less sloppy
Group 2 Choice : Controlled Effortful Deductive Slow Self-aware Rule following	*influencing choice* Zone C [-Safeguard] -Truly libertarian -Least invasive Examples: -Message in hotel room : "69% of hotel guests save energy by re-using their towels" -Providing caloric information on a menu	*manipulation of choice* Zone D -Safeguard -Only acceptable if aimed at compliance with laws Examples: -Asking restaurant guests whether they prefer salad over chips with their burger -Present a commercially attractive option as the default choice

This leads to a different square for consumer goods than presented in Table 1 but to the best of the authors' knowledge there appear to be no obvious advantages for use of 'decisiveness' in nudge taxonomy in this study, aiming at safety application.

Ly et al. (2013) and House et al. (2013) identify four dimensions to structure nudge characteristics:

1. Boosting Self-Control vs. Activating a Desired Behaviour. (Help behave when forgetting vs. Help behave when indifferent)
2. Externally-Imposed vs. Self-Imposed.(self-chosen vs. externally imposed)
3. Mindful vs. Mindless. (conscious thinking vs. automatic response)
4. Encourage vs. Discourage (start or increase a behaviour vs. reduce or stop a behaviour)

Since activating a desired behaviour is externally imposed by definition, this leads to twelve taxonomy bins for nudges. This classification system seems rather detailed, especially considering that the most important nudges are limited in number (Sunstein, 2014; House et al., 2013).

5.3 Finding the key-terms

Talabi & Gibb (2015) present a structure of behavioural factors grouped in seven themes relevant to health and safety performance, found in the building industry. The key terms are: 'Personal values', 'Behaviour based competencies', 'Organisational responsibilities', 'Behaviour modification techniques', 'Personal convictions', 'Behaviour based transition' and 'Behaviour modification tools'. The use of 'nudges' is linked to the latter. The terms 'decisional architecture', 'choice architecture' and 'default' are commonly used in many studies (Thaler & Sunstein, 2008; Smith et al., 2013). Guidance for default setting is proposed using 'Mass defaults': hidden options, forced choice/deny

service, best guess, random default setting and 'Personalised defaults': keeping past customer choices, customer record based smart default, real-time adaptive choice options (Goldstein et al., 2008). The terms 'manipulation', 'reason', 'coercion', 'persuasion', 'induction', 'nudge', 'temptation', 'influencing', 'facilitate' and 'informing' are being used to indicate the severity of the selected way to achieve behaviour change (Tengland, 2012). Several search terms are employed for literature search by Groot Mesken et al. (2014): 'priming', 'framing', 'unconscious', 'automatic', 'implicit influence', 'social norms', 'affect heuristic', 'affect bias'. Talabi & Gibb (2015) use search terms: health, safety, behaviour.
Search attempts for all these terms resulted in a sub-set of terms generating relevant sources (whereas other terms did not): *process, safety, nudge, behaviour, behaviour based safety, ethics, health care, practice, building industry, safety system, historical development, management, incident rates, change, workplace safety, cognitive bias*.

5.4 Inventory of nudge types in literature

Potentially all nudge types could - at some point in time - be of interest for safety application. We felt it would be good to make an inventory of nudge types that have been described and used in practice, either for safety- or for general purpose. We included techniques for mitigating biases which can be developed into nudges, we have simply called them 'nudge types' too for convenience. We came across several nudges with sub-types or variant designs. We grouped them into a single generic nudge type to minimize the inventory size. Several nudge types were found with the same function but different names. In those cases we have chosen the name used most frequently (Groot-Mesken et al., 2014; Thaler & Sunstein, 2008; Ly et al., 2013; Sunstein 2014).
Searching for scientific literature on nudge types, starting from the ones with potential for safety purposes, in this way, a total of 30 nudge types was identified. Below, these are listed, with a brief comment about where they were found and a short description of how they work.

House et al. (2013) use the 12 bins taxonomy proposed by Ly et al. (2013) and group generally applicable nudge types in a 'nudge decision tree', using a mix of types and sub-types.
Current mainstream 'nudges' mentioned as promising areas for safety research are (Levitski, 2014) :

1-*framing* (how to present an issue)
In case of an issue expressed as a profit or loss, people prefer a certain profit and take risk in the face of loss. Loss avoidance is felt stronger than gain perspective. This psychological principle is also known as 'loss aversion'. This nudge type is based on usage of known asymmetrical response of people to 'technically' the same message presented either positive or negative, either as a profit or as a loss, either as avoiding a loss or gaining protection against something. Consistently using earplugs as a preventive hearing protection is achieved better via "you could permanently lose your hearing" than via "you can guard against permanent hearing damage" (HSE, 2003). Negative framing, information expressed as a choice to avoid a loss, has been found to be more effective than positive framing based on gain. Examples of implementations exist (Groot-Mesken et al., 2014; Rothman et al., 1993; Holler et al., 2008; Spence & Pidgeon, 2010; O'Rourke, 2005; Hansen & Jespersen, 2013; Kahneman & Tversky, 1981; OECD, 2010; Jin & Leslie, 2003; Hibbard et al., 2000).

2-*present-bias preference* (quick gain beats long term effect)
Immediate outcome is influencing behaviour more than a long term effect. Focus on direct results is a strong means to influence behaviour. Lack of direct result on the other hand is detrimental for prevention of occupational disease in situations with long duration exposure. Zohar (2003) turned this around and found a large positive behavioural response to daily hearing check results due to workers temporary hearing loss after exposure. This nudge type is also referred to as 'status quo bias'.

3-*social norms / standards* (inform people about what others do)
People want to be part of a group and are strongly influenced by what others in the group do.
People like to belong to the majority and like to follow notions such as: most people disapprove such and so. They even automatically follow example behaviour – *modelling* – to comply with a social norm even though this might be not rational (Dolan et al., 2012). Forming new habits plays a role here too (Lally et al., 2013). *Social norms/standards* includes habit formation, herding, identity, modelling, norms, social proof, use of social norms. Examples of implementations exist (Selinger & Whyte, 2011; Nolan et al., 2008; Thaler & Sunstein, 2008; Groot-Mesken et al., 2014; Goldstein, Cialdini & Griskevicius, 2008; Haines, 1996; Hansen & Jespersen, 2013; Branson, Duffy, Perry et al., 2012; Sunstein, 2006; Ariely et al., 2003; Oullier et al., 2010; Cialdini, 2005*; Avineri, 2014; Linkenbach & Perkins, 2003; Linkenbach & Perkins, 2005; Perkins et al., 2010).

4-*endowment effect* (if the issue is owned it is more important)
People like to plan and make something themselves, even if the actual amount of creativity put in is rather limited. Norton (2012) calls this the "IKEA effect". If workers get the opportunity to come up with their own ideas their compliance behaviour improves because they 'own' a new rule or safety precaution. Safety procedures developed with and by involving workers lead to higher rule compliance (Antonsen, 2009).

5-*foot-in-the-door technique* (start small and build on that)
Somebody that has earlier on agreed to do a small thing A for you is more likely to agree to do the somewhat bigger thing B for you than somebody who is simply asked to do B. This effect has been used in health promotion campaigns (Larkey et al., 1999).

Nudges already being used for traffic safety, in addition to the above types, are (Groot-Mesken et al., 2014) :

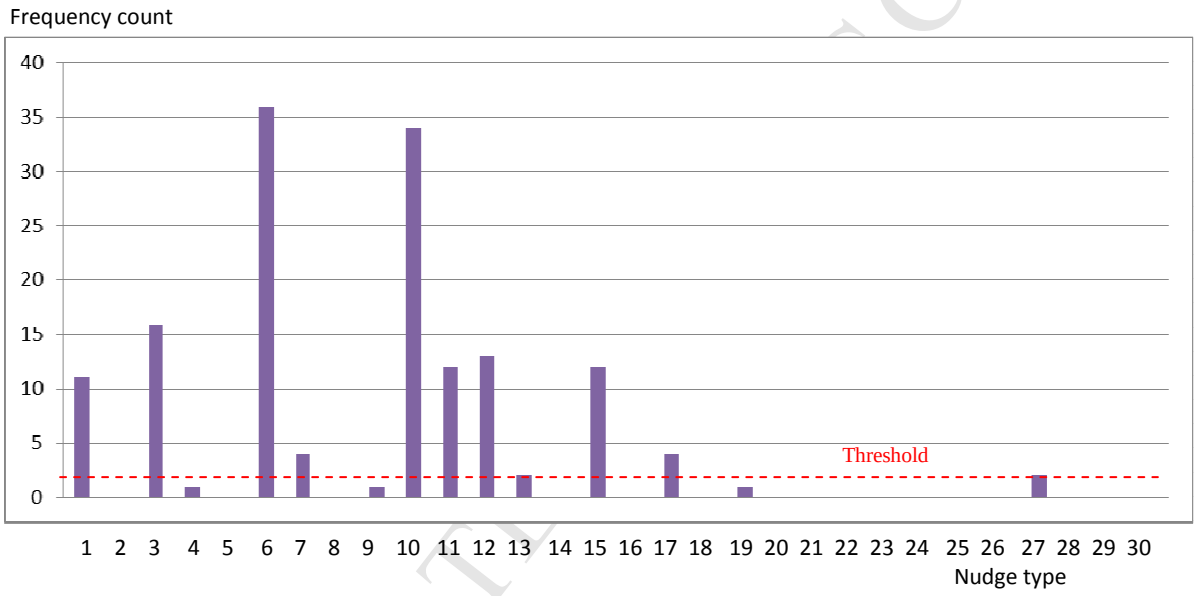
6-*priming* (influences by unconscious cues that create awareness)
Activating unconscious passive external subtle non-enforced awareness by for example a word, an image, a scent, a sound. (Bargh & Huang, 2009; Debets et al., 2010) Priming can be by *guidance from the infrastructure* such as from road corrugations or a traffic sign focuses the mind on a specific hazard to avoid or a decision to take. Priming can also come from *sublimal activation*, the display of an image or message so short that it does not reach the consciousness level. A movement or behaviour may induce unconscious *imitation*, a form of priming. A poster with eyes automatically links to one's reputation. In occupational safety the use of signs, colours and arrows dates back to the first half of the twentieth century. These signs, originating from legislation, standards and safety management, as far as they are not obligatory or prohibitive, qualify as 'nudges' that already exist in process plants. *Priming* includes: guided by infrastructure, imitation, reputation, subliminal activation and warnings both graphic or otherwise. Examples of implementations exist (Groot-Mesken et al., 2014; Holland, Hendriks & Aarts, 2005; Baaren et al., 2003; Debets, Ruitenburg & De Lange, 2010; Charlton, 2006; Lewis-Evans et al., 2012; Goudappel Coffeng, 2013*; Iskarous, Thijssen & Van Leeuwen, 2010; Selinger & Whyte, 2011; Thaler & Sunstein, 2008; Hansen & Jespersen, 2013; Foderaro, 2009*; Meyers et al., 1980; Oullier et al., 2010; Avineri, 2014; Avineri & Goodwin, 2010; Arnold & Lantz, 2007; King & Chapman, 2010; Rumar, 1999; Baillon et al., 2013; Brann 2014*).

7-emotion & mood (emotional associations can shape our actions)
Emotion and mood influence decisions in an automatic way (Dolan et al., 2010). Fright induces prudence, anger leads to risk taking. Fear as an instrument has not been proven

successful in practice (Lavack, 2008). *Affection* on the other hand does create behavioural effects. For example empathy of car drivers is especially important for motorcyclist safety. *Emotion & Mood* also includes 'affect'. Examples of implementations exist (Selinger & Whyte, 2011; Hansen & Jespersen, 2013; Avineri et al., 2014).

Avineri et al. (2014) use the nine 'key effects' of the *Mindspace* behaviour and context approach (Dolan et al., 2010; Dolan et al., 2012) to develop a toolkit for traffic safety. These effects (as far as not already mentioned above) are:

8-*messenger* (who communicates the information influences us)
Information from experts and authority figures (e.g. wearing a uniform or being 'independent') about desirable behaviour decrease violations and increase the weight of the message. People also appreciate information more from people they have a positive feeling for or who are a bit like themselves, like in peer-to-peer sharing of knowledge.



1 framing	11 salience	21 hyperbolic discounting
2 present bias preference	12 commitments	22 choice overload
3 social norms / standards	13 ego	23 information overload
4 endowment effect	14 understand mappings	24 availability bias
5 foot in the door technique	15 feedback	25 representativeness
6 priming	16 expect error	26 anchoring & adjustment
7 emotion & mood	17 structure complex choices	27 ease and convenience
8 messenger	18 confirmation bias	28 disclosure
9 incentives	19 mental accounting	29 reminders
10 defaults	20 willpower	30 elicit implementation intentions

Figure 2 Nudge type inventory and frequency counts as encountered in the references with this study (in total 150 nudge examples analysed)

9-*incentives* (responses to incentives are shaped by mental shortcuts)
Rewarding good behaviour via money, prize or other direct benefits, so 'extrinsic' rewards, creates - if at all - mainly short term behaviour change. Many examples, such as energy

savings displayed real time at home or calories burned at the gym or long distance call costs, are in use.

10-*defaults* (We like to follow pre-set options)
An important tool for choice architects is default setting in such a way that the nudged choice is displayed more prominent than the alternatives. For many people, making a choice requires effort they would rather avoid. Following the default setting, the path of least resistance as Thaler & Sunstein (2008) call it, avoids making an active choice altogether. This even beats the 'status quo'-bias. Guidance for default setting splits them in two major versions: mass defaults (e.g. all customers) and personalized defaults (e.g. based on individual customer track record). Using defaults requires setting up a decision tree (Goldstein et al., 2008). *Defaults* includes 'irrelevant alternatives'. Examples of implementations exist (Selinger & Whyte 2011; Thaler & Sunstein, 2008; Wansink, 2006; Brann, 2014*; Smith et al., 2013; Johnson & Goldstein, 2003; Cronqvist & Thaler, 2004; Park, Jun & MacInnis, 2000; Walt Disney Company 2009*; Halpem, Ubel & Asch, 2007; DECC, 2011*; Faden-Shebaya, 2015; Hansen & Jespersen, 2013; OECD, 2010; Johnson & Goldstein, 2003; Avineri et al., 2014; Walker et al., 2005*; Lai & Carsten, 2012; Reisch et al., 2013; Downs et al., 2009; Taber et al., 2012; Just & Wansink, 2009; Reisch & Gwozdz, 2013).

11-*salience* (people look for new and seemingly relevant things)
People look for new, accessible and simple clues in their immediate surroundings (Dolan et al., 2012). This may be a sound signal, a red light or arrows pointing at something easily attract attention. *Salience* includes 'identity salience'. Examples of implementations exist (Tengland, 2012; Groot-Mesken et al., 2014; Volkswagen, 2009*; Hansen & Jespersen, 2013; Avineri et al., 2014; Darby, 2006; Avineri & Goodwin, 2010; Thaler et al., 2010; Thaler & Sunstein 2008).

12-*commitments* (people like to keep promises and reciprocate acts)
Writing down a promise or a commitment to do or don't do something works as a means to achieve behaviour change. Examples of keeping to a deadline, following a set of safety rules, and don't drink when driving a car are being reported. *Commitments* includes also moral identity, pre-commitment, precommitment strategies. Examples of implementations exist (Thaler & Sunstein, 2008; Breman, 2006; Karlan et al., 2007; Hansen & Jespersen, 2013; Oullier et al., 2010).

13-*ego* (people like to feel better about themselves)
Creating a competition in safer behaviour between groups also works (Houston et al., 2010). Having the 'target audience' to generate publicity material about desired behaviour themselves works too when the motivation includes some form of competition (Thackery et al., 2009).

After reviewing various aspects of human fallibility Thaler & Sunstein (2008) suggest six 'nudge principles' for use by choice architects. We include these (*incentives* and *defaults* are already mentioned above) as nudge types as well:

14-*understand mappings* (presenting the consequences of choice alternatives)
For complicated relations between choices and benefits a 'mapping' technique would be valuable to support decisions. For instance, based on a known past usage mix this could facilitate a choice between telecom providers. *Understand mappings* includes informing people about effect of their past choices (Thaler & Sunstein, 2008).

15-*feedback* (give immediate feedback on behaviour)

Providing direct feedback usually reduces mistakes. In traffic, an indication of measured speed on a display alongside the road nudges drivers towards respecting the speed limit. Feedback can even be used to overcome the present bias preference (Zohar, 1980). Examples of implementations exist (Hansen & Jespersen, 2013; Oullier et al., 2010; Wansink et al., 2009; Thaler & Sunstein, 2008).

16-*expect error* (design to counteract predictable errors)
A task often consists of several steps. People tend to forget to do the last step if the goal has been achieved before that. Leaving the original in the copy machine is an example. If a process is redesigned like the return the credit card by the ATM before the cash is coming out, this type of error is avoided. Ensuring that hoses and end valves for different chemicals cannot be used in wrong combinations because their size or shape is different is an example that exists in the process industry (Thaler & Sunstein, 2008).

17-*structure complex choices* (inform people about peer preference)
When there are many alternatives, like selecting a paint colour or choosing a movie, the technique of collaborative filtering may help. An example of this is to confront people with information about what people with similar taste would like. Examples of implementations exist (Hansen & Jespersen, 2013; ChooseMyPlate.gov, 2016*; Thaler & Sunstein, 2008; Goolsbee, 2006*; Ly et al., 2013; Bettinger et al., 2009; Lusardi et al., 2009).

Finally, as a check for completeness, nudges not specifically identified for use in relation with safety, are explored. Ly et al. (2013) identify suitable nudges for general application purposes via a set of *behavioural influences an heuristics*. This leads to further nudge types not yet mentioned above:

18-*Confirmation bias* (looking more for clues that confirm current insights) (Ly et al., 2013).

19-*Mental accounting* (Money is allocated to different accounts rather than generally usable) *Mental accounting* is also referred to as 'partitioning' (Ly et al., 2013).

20-*Willpower* (Willpower is something that runs out and needs regular topping up) (Ly et al., 2013)

21-*Hyperbolic discounting* (cost and benefit now are felt more important than in the future) (Ly et al., 2013)

22-*Choice overload* (too many alternatives make decision-making hard) The simplification of choice is used (Ly et al., 2013).

23-*Information overload* (too much information makes decision-making hard) The simplification and /or reduction of information is used (Ly et al., 2013).

24-*Availability bias* (known information overrules complex analysis when decision-making) (Ly et al., 2013).

25-*Representativeness* (judge something on similarity rather than on statistical evaluation) (Ly et al., 2013).

26-*Anchoring & Adjustment* (estimate something by using an adjustment onto a reference) (Ly et al., 2013).

Sunstein (2014) highlights ten of the most important nudges for general application. Of these, several are thus far not yet mentioned in the above:

> **27-De-/*increase in ease and convenience*** (make a choice option easier and more fun) This includes reducing/increasing required effort (Sunstein, 2014).
>
> **28-*Disclosure*** (put a behaviour out in the open for everyone to see) (Sunstein, 2014).
>
> **29-*Reminders*** (Provide reminder messages since people forget or postpone actions) (Sunstein, 2014).
>
> **30-*Eliciting implementation intentions*** (confirm already intended behaviour) (Sunstein, 2014).

Some 150 nudge implementation example descriptions were found in the scientific literature referenced in this article. From this exploratory inventory it can be recognized that for some nudge types, implementations are described in detail more frequently (i.e. in more than 2 sources), whereas for some other types such descriptions are quite rare or not found at all. A simple count per nudge type description within this inventory leads to the frequency count distribution plot in Figure 2. This shows some 9 higher frequency nudge types (6,10,3,12,11,15,1,7 and 17),several low frequency nudge types (4,9,13,19 and 27) and zero frequency nudge types (2,5,8,14,16, 20-26 and 28-30).
Though this is only indicative, we contend that the higher frequency counts do point at nudge types with more practice application experience, suggesting a stronger evidence base.
We contend that the lack of implementation descriptions for a number of nudge types in scientific literature found in this exploratory study and the apparent lack of relevance for safety of several nudge types (Levitski, 2014; Groot-Mesken et al., 2014; Avineri et al., 2014) are sufficient basis for selecting a first set of 9 potentially interesting nudge types for safety management. These appear in the table 2 left column.
This shortlist of 9 nudge types in total, includes 95% of the nudge examples described in the referenced literature. We observe that the nudge types 2-*present-bias-preference*, 4-*endowment effect* and 5-*foot-in-the-door-technique,* identified by Levitski (2014) as "*promising areas for safety research*", do not appear in this shortlist due to lack of example descriptions from practice in scientific literature.
The distribution over categories automatic/choice, transparent/non-transparent and application zones A, B, C and D, as found for the example nudges in literature (see Table 2), shows whether a nudge type mainly addresses automatic behaviour or conscious choices.

Table 2 Shortlist of 9 frequently described nudge examples in literature with indicative count percentages per nudge type and their distribution over group, transparency level and application zone.

Nudge type nr	Percent Description	Frequency Count	Group 1 automatic	Group 2 choice	Trans-parent	Non trans-parent	Zone A	Zone B	Zone C	Zone D
6	priming	24	23	1	9	15	8	15	1	0
10	defaults	23	14	9	9	13	7	7	3	6
3	social norms	11	31	8	8	3	1	1	7	1
12	commitment	9	2	8	9	0	1	0	8	0

11	salience	8	2	6	7	1	1	1	6	0
15	feedback	8	2	6	8	0	2	0	6	0
1	framing	7	0	5	2	5	1	1	1	5
7	emotion	3	0	3	2	1	0	0	2	1
17	structuring	3	0	3	3	0	0	0	3	0
Total		95 %	46 %	49 %	58 %	38 %	21 %	25 %	36 %	13 %

5.5 Areas for safety improvement in the process industry

Although 'nudge' is a new term, there are many existing nudges in use for many decades in support of safety in many areas in society. Generally used traffic- and warning signs qualify as examples of type 6-*priming*. The nudge design consists of a sign and priming is the bias targeted. Signs are also applied in process industry plants. They clarify rules and point at dangers. Type 6-*priming* nudges create safety awareness, mainly in physical and dynamic environments.

So, what about the other nudge types and situations? The generic question in this case is: "could nudge type X be suitable for application in safety improvement area Y?

Hopkins (2011) identifies areas for risk-taking behaviour improvement in the workplace. We focused on worker behaviour and included these as "safety improvement areas" in table 3.

The main improvement potential resides with unsafe acts by workers and with insufficient preventive measures taken by company safety management. We consider the company safety management part only being relevant as far as it directly relates to worker behaviour. Not all the areas for risk-taking behaviour improvement, identified by Hopkins (2011), offer potential for nudge application.

Looking at occupational accidents in the Netherlands, as recorded at RIVM in the Story-Builder database, only 5 of in total 36 accident types represent 73% of the accidents (RIVM, 2016*). These occupational accident types are applicable in all sectors, including the process industry. They are:

Falling from height (29%)
Contact with moving machine parts (22%)
Falling objects (13%)
Collision of pedestrian and vehicle (4.4%)
Entrapment by machine and other object (4.2%)
Remaining 29 other accident types (27%)

Causes of these most frequent accidents lie a.o. in wrong movements by a worker, incorrect use or absence of physical protective gear or safety provisions on machines and in poor visibility of workers and vehicles (RIVM, 2016*). Up to 90% of all accidents are human error related (Kletz, 2001) and therefore also these frequent types are important to consider when improving safety by implementing nudges intending to change behaviour.

Nudges could counteract both the automatic unsafe behaviour of workers and the unsafe choices workers can make. Such unsafe choices may occur either if no rules or guidance are in place, or if economic- and safety interests are in conflict and rules might be violated (Zohar et al., 2005).

This neither denies nor solves the safety problems caused by imperfect procedures or incorrect instructions by teamleaders. A nudge could help to better follow the rules, assuming those are correct.

In some of the improvement areas the group 1, automatic action behaviour, is more important, whereas in other areas this would be group 2, choice action behaviour. In some areas both groups can play a role.

This distinction is important as a usability appraisal criterion since it qualifies or disqualifies a specific nudge type per specific improvement area. Some of the nudges in the Table 2 short list address automatic behaviour, others concern choice situations or both. This leads to a set of proposed safety nudges for the process industry, suitable for use in each risk taking behaviour improvement area, as presented in Table 3. In all except two of Hopkins' (2011) improvement areas (nr 11 and 12 in Table 3) there are nudges available for use. For example: a worker taking a casual attitude towards rule compliance consciously chooses not to follow a known rule (IA6). A nudge influencing automatic system 1 behaviour would simply not work here. On the other hand a nudge based on influencing the workers' bad system 2 choice could have a corrective effect on his behaviour.

Table 3 Safety improvement areas in the process industry according to Hopkins (2011) and suitable nudge types to be used by safety management.

Risk taking Improvement Area (IA)		Worker behaviour part: Unsafe acts	Safety Management part: Enabling unsafe choices	Suitable nudge types:
IA1	take it easy	choice	Lacking awareness	1,3,7,10,11,12,15,17
IA2	production pressure	automatic	Economic priority	6,10,11
IA3	work at the limit of one's skills	automatic	Poor training	6,10,11
IA4	pressure from employers	automatic, choice	Economic priority	1,3,6,7,10,11,12,15,17
IA5	fatigue	automatic, choice	Economic priority	1,3,6,7,10,11,12,15,17
IA6	consider rules to be unnecessary	choice	Lacking awareness	1,3,7,10,11,12,15,17
IA7	casual attitude towards compliance	choice	Lacking awareness	1,3,7,10,11,12,15,17
IA8	undermined risk awareness	automatic, choice	Poor instructions	1,3,6,7,10,11,12,15,17
IA9	quick decision-making	choice	Poor emergency training	1,3,7,10,11,12,15,17
IA10	goal oriented rule not translated to practical rule	choice	Poor instructions	1,3,7,10,11,12,15,17
IA11	not at ALARP level	-	Poor safety measures	-
IA12	not according to standards	-	Poor safety measures	-

5.6 Theoretical framework

Workers in a safety controlled environment have been subject of scientific study for many years. Hale (2000) underlines the importance of natural groups among company personnel for safety as they are holding on to their own values and standards. Guldenmund (2000) defines a framework for safety culture. Around a core of basic assumption this framework has an 'espoused values' and 'beliefs' layer, in turn surrounded by observable safety culture elements. Wiegmann et al. (2002) and Mohamed (2003) refine the definition of safety culture and distinguish safety climate as a separate aspect of safety culture. Hudson (2007) underpins trust, accountability and information as necessities for a safer culture. Reniers et al. (2007) identify a three dimensional space for observable accident

prevention: *people, procedures and technology*. (P2T model). Meyer & Reniers (2016) use an aggregated model: *The Egg Aggregated Model* (TEAM model) of safety culture to map the safety culture terrain. The TEAM model assigns behavioural factors to three separate area's:

1) intention to behave, dominated by personal psychological factors
2) safety climate, controlled by perceptual factors
3) measured safety, determined by observable technical, procedural/organisational and behavioural factors.

Since human behaviour has a bearing on all three areas it is safe to say that safety culture provides an environment for nudge development. Because nudges influence individual behaviour the personal psychological factors are of key importance here. These are:

-Individual attitude towards a behaviour
-Skills, ability and individual knowledge
-Personal characteristics, e.g. risk perception.

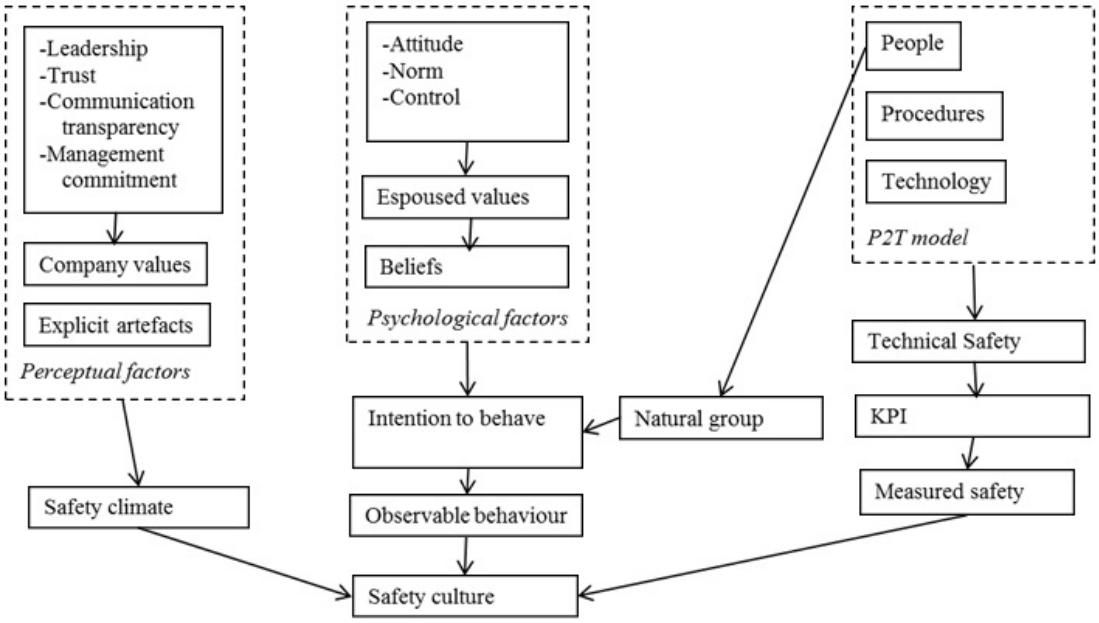


Figure 3 Nudge development reference framework

Kahneman (2011) underlines that a persons' environment is an important factor for behaviour, so this would equally apply to organisations and workers. Neal et al. (2004) investigated safety climate influences on worker behaviour and they confirm this relationship.

Avineri et al. (2014) uses the *Theory of Planned behaviour* (TPB model) to explain intention (Ajzen 1988; 1991). In this model Musselwhite et al. (2010) link behaviour to intention with three determining factors: attitude, norm and control. Although these factors differ in wording from the psychological factors defined by Meyer & Reniers (2016) they also overlap. We therefore interpreted the psychological factors as follows:

Attitude : attitude towards a behaviour ("to my opinion doing routine checks is necessary"),
Norm : subjective norm ("my colleague tells me he skips this routine check too"), which includes risk perception and personal characteristics,
Control : perceived control of the behaviour ("I do routine checks as often as I think is safe"), which is a result of personal skills and knowledge.

Safety climate consists of shared perceptions on the work floor and can be known via a.o. explicit artefacts and values of a company such as Leadership, Trust, Communication transparency and Management commitment (Meyer & Reniers, 2016; Wiegmann et al., 2002). Observable safety is

measurable via document study and quantitative indicator values originating from the P2T model space (Meyer & Reniers, 2016).
Although an overall model incorporating safety culture and safety climate, does not exist (Reniers et al., 2011) the above models do allow the construction of a reference framework for nudge development, as shown in Figure 3.

5.7 Grey literature contribution
Among the literature sources referenced in this study containing nudge example descriptions, 'grey' literature (Wessels, 1997) plays a minor role. Although grey literature presents interesting examples applied in practice, only few of these show potential for the process industry. Citations of 'grey' sources are marked with * after the year of publication.

5.8 Nudge example library
Other application areas provide a plethora of nudge examples. This information is not disclosed on a practical implementation level to safety engineers – acting as 'choice architects' and 'psychologists' – when using nudges in the process industry, however. We included detailed references with this study on the nudge types presented in table 2.

5.9 Guidance for the development, implementation and evaluation of a safety nudge
There is no established method or formula available to successfully design and develop a 'nudge' (Selinger & Whyte, 2011; Tengland, 2012). This infers that a practical way how to go about creating a process safety nudge, must be found. Two recent examples of nudge development for road safety provide such practical information: Groot-Mesken et al. (2014) and Avineri et al. (2014). Both have made an inventory of nudge examples from literature and compared those with a reference framework. Avineri et al. (2014) used the '9 *mindspace effects*' as reference framework, Groot-Mesken et al. (2014) used a small set of 4 nudge types: priming, framing, social norms and emotions. Neither of these two examples describe the design and development of a nudge in detail though. Ly et al. (2013) use a decision making tree and a set of four questions to go through their tree, and in so doing, select possible nudges. Then follows an iterative process where leverage, priority and effectiveness testing are to deliver a nudge for implementation. Gathering things that need to happen during development of a nudge from Groot-Mesken et al. (2014), Avineri et al. (2014) and Ly et al. (2013) resulted in a logical sequence. We found no conflicting views or unfinished debates on these practices. We therefore propose, as the way to go about implementing a nudge, to follow 6 steps:

Step 1 ***Assess the situation at hand***
The situation at hand can best be compared to the risk taking improvement areas listed in Table 3. Selecting one of the risk taking improvement areas as a best fit, based on similarity, will do. For example: When a sudden fire catches the attention of a safety conscious worker, he decides to run towards it and closes a valve, bringing himself in harm's way. This behaviour would fit in the category 'quick decision making'.

Step 2 ***Focus on individual worker behaviour***
From the theoretical reference framework in Figure 3 it becomes clear that nudges must be aimed at the psychological factors determining the individual worker's intention and the resulting (observable) behaviour. A nudge action can address automatic- or choice behaviour, resulting from espoused values and beliefs, via the attitude, norm and control psychological factors. The behaviour to be addressed can thus be defined. For example: if a worker is convinced he can control the imminent danger by quickly closing a valve he might run towards a starting fire rather than away from it. The reason behind this might be a lack of emergency training. The behaviour to deal with is then: conscious 'Choice' in relation to 'Control'.

Other perceptual factors belonging to safety climate, directions or rules originating from safety management procedures, and peer pressure, in the natural group of workers the individual belongs to, may add to the workers' intention to behave, but are not easily improved via nudging the workers themselves. For example: if management commitment to safe work is poor, a worker may develop a casual attitude towards safety measures. The reverse, more dedicated workers to change management commitment to safety for the better, is less likely.

Step 3 ***Select a nudge type***

Next, Table 3 allows matching of the situation at hand with preselected nudge types. This match results in a set of suitable nudge types for further development. Based on the application zones in Table 1 and the shortlist in Table 2 it is possible to select the least objectionable and most frequently applied nudge type within the match set. For example: the worker running towards the fire might be nudged via types 10, 3, 1, 11, 12, 15 and 7 according to Table 3. Type 10 might raise some ethical questions, thus making type 3, 'social norms' in table 2 the least objectionable, and most frequently applied one, therefore in this example the preferred and suitable nudge type. The other nudge types remain possible too. Often there are already nudges in place in the specific situation at hand. Usually these are type *6*-p*riming* nudges (e.g. warning signs).

Step 4 ***Design, construct and pre-test the nudge***

The design of the selected nudge type application in the situation at hand can best be done using the referenced sources on existing well proven examples of nudges used outside the process industry. Example: the worker running towards the fire might be nudged with 'social norms' in a way similar to hotel guests getting a room note on environmental savings through reuse of their towels (Groot-Mesken et al., 2014). A company might convey a message to its workers stating: "80% of the workers in process industry wear fire resistant overalls at all times." Such a message can be part of a training or be a message on the wall in the canteen, etc.

Worker behaviour needs to be observed both before (pre-test) and after (evaluation test) introduction of a 'nudge' on the shop floor. This allows later testing and evaluation of the duration and magnitude of its effect. To observe effect over time, sufficient observation time and, after a while, re-observation opportunity are necessary.

Step 5 ***Implement the nudge***

After introduction of the nudge, worker behaviour needs to be observed for a while to validate the nudge effectiveness and segregate it from any environmental disturbing effects. A proper case study method should be applied (Yin et al., 2006). Then the nudge may need 'tweaking' or 'tinkering' and another check on worker behaviour. If the effectiveness on short term is satisfactorily, also re-check the effectiveness after a longer period.

Step 6 ***Evaluate the nudge***

Finally it is recommended to methodically evaluate both the effectiveness and the development process (Ly et al., 2013). Van der Heijden et al. (2015) suggest comparison of relative and absolute performance of a nudge in a specific situation with both a pre-set goal and the situation without the nudge. We contend this will support future nudge developments for safety in the process industry. Publishing the evaluation report will add to the existing evidence and contributes to the cause of safe work in the process industry.

By using the above steps as guidance, starting from the need for safety improvement and from suitable nudge types, both as presented in table 3, any number of practice-oriented implementation- and evaluation nudging projects can be defined.

6.Discussion

We need to point out that none of the 'nudges' in the inventory presented in this study are supported by evidence if it comes to the specific application area of safety management in the process industry. Also, no nudge implementations in the process industry are as yet available for evaluation. This exploratory study was designed to find frequently mentioned nudge types from scientific literature, under the assumption that these would therefore be supported by evidence. Considering that the shortlist in Table 2 contains 95% of the nudge implementation example descriptions found in literature as referenced in this study, we argue it to be a sufficiently complete nudge types set for a start.

This set of 9 nudge types proposed for use in the process industry is supported by evidence in other application areas, although such evidence has limitations of several kinds:

Firstly there is *uncertainty about the effects* of nudges, even within the bounds of their original application. An example of this is the spread in reported results on the effect of narrowing roads on vehicle speed (Deller, 2013). Groot-Mesken et al. (2014) conclude that the magnitude of its effects on behaviour by the 4 nudge types they investigated are on the one hand proven in many studies but on the other hand difficult to make visible. Their experiment with *priming* did not materialize into significant effect on behaviour of schoolkids. Avineri et al. (2014) conclude, based on their study of 9 nudge types in the *mindspace* framework, that the nudge concept works best on system 1 (automatic) behaviour. In contrast to, say, education as a means, nudges do not add to the individuals knowledge or values. The effects of nudges are vulnerable to the context which might change beyond control, leading to a different and unintended outcome. Avineri et al. (2014) propose to critically evaluate present evidence, inform road safety staff about nudges as a potential tool, do further research on contextual aspects, to introduce empirical and controlled studies and begin with systematic evaluation. Hence, we observe, for the time being, that the effectiveness of the nudge types proposed for application in the process industry remains to be proven.

Secondly, the *validation and empirical backing* of nudges is in some cases flawed or missing alltogether, due to methodical issues. The definition of 'nudges' is not settled and no established method for systematical validation and evaluation of their effectiveness is available (Selinger & Whyte, 2011; Tengland, 2012). Caution is needed when introducing a 'successful' nudge in another situation. Neal et al. (2004) review studies about the attitudes towards safety, individual differences and perceptions of the safety climate. They conclude that safety climate does influence an individuals' safety behaviour. Zohar et al. (2005) find variations even between groups within a single organisation depending on team leader personal approaches and production pressure. Others criticize the dependency of nudge outcome for different social cultural backgrounds, i.e. minority-, migrant-, religious- or age- groups (Selinger & Whyte, 2011; Bovens, 2010).

We therefore contend that, since both social- and safety cultural differences among workers exist, there is a vulnerability of achieved nudge effects for such differences to consider. Therefore, validation of any nudge introduced in any work environment would be always needed.

Thirdly, the *consistency of the evidence in time* is being challenged in some cases. A single short duration trial under test conditions does not predict nudge effectiveness over time in practice (Wansink, 2006).

Fourthly, the *sensitivity of nudge design* is a concern. Small changes in 'nudge' design may result in large differences in outcome. This implies that the achieved effects are sensitive to minor details which may not be under control. An example of such design sensitivity is the wording of the text in a hotel room on saving energy by re-using towels (Cialdini, 2005*).

Fifthly, nudges in a specific situation may simply be *not generally applicable.* An example of this is the relation between lemon scent and cleaning behaviour observed in groups of psychology students eating cookies (Holland et al., 2005).

Variety of nudge types

The variety of nudge types and their application areas – also other than 'safety' related – appears to be huge. Our study was designed to explore possibilities for nudge application in the process industry. Besides nudges not generally applicable there may be nudges with a potentially wider range of application in the industrial sector. This was outside the scope of this study. We believe that future research may result in similar sets of safety nudges applicable in other industrial sectors.

Limitations to usage

There is a fundamental limitation to the use of nudges. If it comes to 'life or death' matters, a nudge is not a 'classic' safety measure which can be designed to avoid the problem alltogether. A nudge may increase the percentage of e.g. rule compliance and improve worker behaviour related to safety, but it does not constitute a sturdy 'barrier' in a causal tree.

We further contend that nudging might best be aimed at irrational and non-compliant behaviour, the 'left-overs' from the safety management system. Perfectly rational human beings, the '*econs*' as Thaler & Sunstein (2008) call them, may never need a nudge when rules are equally perfect. Since procedures and organisations show flaws, just as humans do, nudges can be designed to both help improve rule compliance and also to reduce irrational behaviour by workers in hazardous circumstances.

Ethical concerns

Some ethical concerns need to be addressed before introduction of any of the proposed nudges on the shop floor. Among the nine identified usable nudge types there are two (the numbers 6-*Priming* and 10-*Defaults*) which might raise ethical concerns in any of the process industry safety improvement areas. Nudging of the general population by their government does not always respect the democratic communication principles identified by Habermas (1981). Government nudges, seen as a part of societal dialogue, would have to be in line with four criteria: understandable, truthful, sincere and respectful. These criteria shed another light on 'general public' nudges than the proposed Rawls (1971) publicity principle criterion does. The Habermas criteria are not applied in many cases. It is –for the time being – not clear what makes exertion of power via knowledge by the few, in this case by means of a nudge, justifiable in general practice for the many (Estlund, 1993). The psychology- and behavioural economics domains provide ways to influence people while taking e.g. health related decisions or making choices in e.g. a shop or restaurant (Blumenthal-Barby et al., 2012). The debate about whether this is an ethical mishap, since autonomy of a patient is violated by absence of 'informed consent', is ongoing. Gentle 'nudges', intended to promote a healthy lifestyle, might avoid medical problems. Blumenthal-Barby et al. (2015) argue that these gentle pushes in the right direction would always qualify as a justified cause, even if they aren't an expression of the patients free will. One might argue that nudging workers – be it gently or not – towards safer behaviour in a hazardous work environment would be equally justified.

Nudges and Safety Management Systems

In the chemical and process industry, regulators look at both occupational safety and at major hazard control under the EU Seveso III directive. Risk assessments, compliance with standards and safety management systems are their focal points. Hale & Swuste (1998) assess the hierarchy of rules in a company environment and allocate increasing level numbers for increasingly practical rule types in a working environment. Safe work legislation would be a level 1 rule. Regulators look at rule compliance in high risk companies in two ways:

-whether the goal oriented level 2 rule is properly translated into practical company rules, and

-whether these rules are properly implemented as level 3 work instructions (Hopkins, 2011).

So, 'nudges', if considered as a part of a safety management system, could be classified as 'level 4' rules.

Evaluation of effectiveness

Regulators would need to assess a nudge's effectiveness, implying the process industry ought to provide valid evidence in support of that upon inspection.

Selinger & Whyte (2011) identify a lack of UK government nudge evaluations in 2011. Four years later Van der Heijden et al. (2015) present a range of nudge evaluations varying between highly successful, doubtful or failure with even opposite results than intended. They argue that the evidence base shows weaknesses and a robust evaluation method for nudges is lacking. In cases where any government wants to nudge the general public, such nudging requires legitimacy, transparency and safeguards to ensure accountability and effectiveness in achieving a politically determined collective goal.

A possible suggestion may be related to the monitoring of safety key performance indicators (KPI). A safety KPI provides a setting wherein nudge evaluation is supported by quantifiable parameters. A specific KPIs set may be object of the analysis through specific monitoring and selected nudges might be oriented towards each KPI to achieve a desired goal-value. Since a nudge might loose its merit after a while, such a link with a monitoring system could enhance its long term performance. This line of thought deserves further empirical research.

Process Industry

This does not directly apply to nudges in the process industry, since employers simply must keep their workers safe. It would seem logic however to ensure at least the effectiveness of any nudging intended as a contribution to safety as far as not otherwise regulated. Van der Heijden et al. (2015) – the only literature source on nudge evaluation methods found in this study – suggest explorative studies comparing relative and absolute performance of a nudge in a specific situation with both a pre-set goal and with the situation as it was without the nudge.

We believe case studies with specific nudges being introduced and evaluated in specific company situations would be necessary to proceed along this path. Comparison to similar nudge type applications in other areas can be used to support the evidence found in the Process Industry.

7.Conclusion

In current industrial practice already many 'nudges' influence worker behaviour. The completeness of the 'nudge' inventory presented here must be questioned as it depends on a definition still being debated and even existing health and safety signs and markings could qualify as 'nudges'. They have just never been called 'nudges' before. A wide variety of new nudge concepts emerges from behavioural economics. Literature reports that these have been successfully introduced in many application areas but they are hardly – if at all – applied to safety in the process industry.

It would appear that nudges constitute a large but underutilized safety improvement potential for the process industry. Nudges can add to safety in the process industry already today, using 9 existing nudge types supported by evidence from available examples in other application areas. A development, implementation and evaluation approach for safety nudges in the process industry is proposed. Caution is advised though, since a few specific nudge types may raise ethical concerns. Also the empirical evidence of nudge effectiveness is being criticised in some cases and their application may show vulnerability to cultural differences. In-depth understanding of the way nudges work, guidance on their development and rigorous empirical evaluation methods are lacking. Nudge

type combinations, mutually excluding nudge types, nor synergy between nudge types have been further investigated in this study but might hold possibilities for future research. We therefore recommend future research to address these areas.

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