Making sense of bridge design: how seamanship may challenge technology-as-designed

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A ship bridge may be looked upon as a compromise between the ideas of the designers and equipment manufacturers on one hand and the seamanship of the end-users on the other. How electronic navigation tools and the overall bridge system is designed influence operators sensemaking - their possibility to assert meaning to their environment and the situation at hand. Inappropriate technical or functional design may be the result of a combination of factors. It may be difficult for designers and engineers involved in bridge design to foresee how the technology will be used in a context they are not familiar with and do not easily have access to. Involving the end-users in the design process may reveal aspects of the real-world context and end-user preferences otherwise not accessible to "outsiders". One such aspect is seamanship – the informal ideas, values and norms that contribute to how work is performed and how professionals adapt technology and procedures to their work situation. These adaptations reflect the gap between technology-as-designed and technology-as-used. This article reports from the ongoing project SMACS – Sensemaking in Safety-critical situations, which aims to contribute to reduce the gap between design intentions and operative experience. A qualitative research approach has been applied and the data collected so far from observations and interviews on board maritime vessels is presented and discussed.

Keywords: technology-as-used, seamanship, sensemaking, ship bridge design, electronic navigation tools, human factors.

1. Introduction

On the early morning of December 3rd 2016 the Spain registered bulk carrier *Muros* was on passage between Teesport, UK and Rochefort, France (MAIB, 2017). It was dark, but visibility was good and the sea state moderate. The vessel was on autopilot following the passage plan in the electronic chart display and information system (ECDIS). The second officer had the navigational watch supported by an able seaman as lookout. Their bridge watch was very quiet with few other vessels in the vicinity as they were approaching Haisborough Sand on the east coast of the United Kingdom. At 02:48 AM they suddenly felt a change in the vessel's motion and noticed the speed was quickly reduced. The master was called to the bridge and realized that *Muros* had ran aground. Fortunately, this incident did not result in any injuries or pollution and the vessel was re-floated 6 days later and towed to shore to repair damage to the rudder. The investigation report concluded that the track over Haisborough Sand was unsafe given the vessel's draught and depth of water available. The report also identified several safety issues directly contributing to the accident. Although the route was planned and monitored using the vessel's ECDIS, the "system and procedural safeguards intended to prevent grounding were either overlooked, disabled or ignored". E.g. the track over Haisborough Sand was not planned or checked in an appropriate scale chart and the audible alarm and guard zone was disabled. The report states that "The ECDIS on board *Muros* had not been used as expected by the regulators or equipment manufacturers." (MAIB, 2017). This sentence caught our attention as it demonstrates a gap between how regulators and equipment manufacturers imagine work onboard a maritime vessel is performed and how the seafarers actually go about solving their daily tasks.

There are many examples were the use or non-use of electronic navigation equipment contributes to incidents and accidents at sea (Chauvin et al. 2013, MAIB 2017, Nilsen et al. 2017). Often the explanation or cause of these type of maritime accidents have been attributed to "human error". Some scholars have reported that over 80 % of marine accidents are caused or influenced by human and organizational factors (Dhillon, 2007). However, Lützhöft and Vu (2018) states that "it is faulty design, not 'human error', that is the primary, or latent, reason behind accidents in the maritime industry." Industrial, interaction and graphic designers are increasingly being involved in development of products for the maritime domain. This domain may be unfamiliar to these designers as well as environmentally and culturally different from contexts onshore (Lurås and Nordby, 2014). In this paper we discuss how

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the gap between technology-as-designed and technology-as-used is rooted in professional culture or seamanship - the informal ideas, values and norms that contribute to how work is performed and how professionals adapt technology and procedures to their work situation (Lamvik et al., 2010).

This work is part of an ongoing project called Sensemaking in safety-critical situations (SMACS) where the main goal is to increase safety at sea through development of human-machine interfaces (HMI) and training methods that facilitates seafarer's sensemaking.

1.1 *The bridge environment*

Since automation and computerized systems were introduced in the 1970s there has been a steady increase in digitalized products, applications and services introduced to the maritime domain. The navigators work has changed, from being outside, under open air and exposed to all sorts of weather and temperatures, to increasingly become more and more dependent on *representations* of the outside world. They have to rely upon technical instruments and screens, to acquire the same information. During the last decades this development has been rapid, illustrated by the number of items of equipment at the main workstation increased from 22 to 40 during the period of 1990 to 2006 (Lützhöft et al., 2006).

This development is part of a larger picture. The next industrial revolution "Industry 4.0" is taking place right now (Hermann et al., 2015). In shipping, this revolution is sometimes called Shipping 4.0 or cyber-shipping (Rødseth et al., 2016). Shipping 4.0 includes extensive use of new technology like Cyber-Physical Systems (CPS), Internet of Things (IoT) and the Internet of Services (IoS) and thereby provide the possibility to access new data and information and apply new platforms to assist in decision support(Ibid). IMO initiated the e-navigation strategy in 2005, described as "the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea" (IMO, 2015). However, IMO has also recognized that "if current technological advances continue without proper co-ordination there is a risk that the future development of marine navigation systems will be hampered through a lack of standardization on board and ashore, incompatibility between vessels and an increased and unnecessary level of complexity" (IMO, 2015).

E-navigation and cyber-shipping has led to what can be seen as a digitalization of the seafarers sensemaking, meaning that sensemaking is now more based on interpretation of presentations on screens than first-hand experience based on tactile and tangible involvement.

1.2 *Theoretical foundation*

The SMACS-project has chosen sensemaking as the theoretical basis for the planned research activities. Sensemaking has been described as consisting of three interrelated processes: creation, interpretation and enactment (Sandberg and Tsoukas, 2015). The creation process involves noticing and extracting cues from the environment. The extracted cues are interpreted to make an initial sense, followed by action or enactment. The actions create a slightly different or new environment where further cues can be drawn. This is an ongoing cycle that most of the time is swift and mundane and other times can be more deliberate.

Weick (1995) described sensemaking as being "grounded in identity construction". He argued that identities are constructed out of the process of interaction, people learn about their identity by projecting them into the environment and observing the consequences. Identity is not constant, people experience a changing sense of self as they shift among interactions and try to decide which self is appropriate in a particular situation. According to Weick identity is crucial for sensemaking "What the situation means is defined by who I become while dealing with it or what or who I represent" (Weick, 1995 p. 24). However, the direction of causality goes both ways, identity influence sensemaking but sensemaking also influence the definition of self.

The importance of identity for sensemaking becomes especially evident in organizational crises or change, when identity might be threatened (Maitlis and Sonenshein, 2010). A threatened identity may constrain action, as seen in Weick's analysis of the Mann Gulch fire where 13 firefighters died (Weick, 1993). The foreman realized the severity of their situation and told the retreating crew to throw away their tools, however without their tools they would turn "from a team of firefighters to a group of endangered individuals who were running from a fire" (Maitlis and Sonenshein, 2010). In this case the collapse of sensemaking had catastrophic consequences.

In the maritime sector, professional identity is denoted with the term *seamanship*. The notion seamanship may vary with different areas of use, whether in maritime regulations, accident investigations or in media. None of these meanings may be consistent with how seafarers understand or use the term (Bye et al., 2015). According to Knudsen (2009) seamanship is a blend of professional knowledge, professional pride and experience-based common sense, as well as having a social and ethical dimension. Seafarers use it as a standard to describe life at sea, e.g. the social abilities needed, as well as a more general attitude towards life. Good seamanship is closely related to professional identity and is also used to separate "us" from "them", meaning separating "real seafarers" from "others". "The others" may be people on land, employees in shipping companies, representatives from authorities, newly qualified seafarers without sailing time or foreigners (Antonsen and Bye, 2015). Also, the work by Helmreich and Merritt (1998) can be used to illustrate professional culture in maritime industry. Although, their work is pivoting around the sectors of aviation and medicine, Helmrech and Merritt's understanding of profession as shared and taken-for-granted values among colleagues, is also relevant for a deeper comprehension of everyday work in the maritime sector.

Good seamanship today is probably different from what was seen as good seamanship a few decades ago (Bye et al., 2015) as the highly dynamic and evolving nature of professional identity are related to the introduction of new technology (Korica and Molloy, 2010).

2. Method

The data collection in this project is ongoing. This paper reports from the data collected so far. Semi-structured interviews have been performed with eight officers during short visits on-board three passenger ships sailing on the Norwegian coast. Several days of observations and semi-structured interviews was performed with eight officers on-board two offshore supply vessels operating in the North Sea. In addition, two semi-structured interviews have been performed with employees of a maritime equipment manufacturer. The interviews were either recorded and transcribed, or notes were written during the conversations or immediately after. The data was subjected to analysis were themes related to the research focus, interaction with technology, sensemaking and seamanship, were drawn out. The findings are condensed and presented in chapter three. The cited quotations have been translated from Norwegian.

The discussion also draws on one of the authors having several years of experience of research within the maritime sector, including ethnographic studies onboard a variety of merchant ships in international trade. Through his PhD dissertation pivoting around the Filipino seafarer in international fleet (Lamvik, 2002) and an article with the same topic (Lamvik, 2012), Lamvik has addressed important issues in the maritime sector over last years. If you also add a broad set of projects the last 20 years, he has from different angels discussed, interpreted and analysed the complex field of cultural differenced, work practice and safety. Also, the specific issue of maritime training and competence, and the crucial concept of seamanship, has been some running themes in his scientific career.

3. Findings

3.1 *Retrofitted bridges*

The passenger vessels visited was built in the 1980s and 1990s. The bridges had equipment from several different manufacturers and had developed over the years as new equipment had been installed due to new regulations or replacement of non-functioning equipment. There were many examples of basic ergonomic principles not followed, e.g. small and in-adjustable text made it impossible to read text on screens from normal working position, several screens without dimming function (which impairs night vision), no possibility to adjust consoles/work places to accommodate crew with differing heights, and equipment that could not be reached from normal working position. In one ship the work position needed to reach the handles made the officer be positioned with his back towards the window he needed to look out of during docking. Other ships had an overall shape of the bridge that obstructed line of sight sideways.

The officers showed us many examples of equipment with design solutions they found impractical and annoying. For instance, very small handles or knobs that were difficult to grasp especially in the dark or in high sea state. Other examples were handles without feedback, many non-functioning buttons, and many audible alarms coming from different equipment around the bridge. The alarms were ranging from smoke detectors distributed around the vessel to alarms every time there was a course change performed by the autopilot. The alarms had similar sound making them difficult to distinguish from each other. A seemingly simple task like switching on the wipers were cumbersome either due to several panels distributed throughout the bridge or touchscreens with intricate menus and poorly functioning touch-function.

The visual impression was that these bridges were cluttered with equipment, buttons and levers, seemingly randomly placed in the consoles. One example of random placement was a fuel-meter, transmitting the consumption of fuel to the shipping company on shore. The screen for this fuel-meter was centrally placed in the console in front of the navigators' main working position. This screen was not relevant for navigation tasks and did not have a dimming function needed not to obstruct night-vision.

Touch screens were a topic most of the officers on these boats pointed out as a source of frustration. The touch screens available did not respond very well to touch, they had to press many times before the screen responded. The officers found it impractical to click through lengthy menus to find the desired functions. They clearly expressed that they preferred buttons or switches that were easily located and that gave immediate and clear feedback.

It was observed that the crew implemented different forms of adaptations and workarounds on these bridges. They were standing on pallets or climbing on the consoles to reach necessary equipment. They covered up screens to dim them, they had different ways of marking which buttons or levers should be used or buttons that were out of order and they added additional equipment like computer mouse.

3.2 *Design involving the end-user*

The two offshore supply ships visited was built in 2014 and 2016. They were equipped with a newly developed bridge concept where the manufacturer had emphasized end-user involvement during development.

In general, when the officers described this bridge, they used words like “user-friendly”, “well arranged”, “you have everything you need around you” and that after working with this bridge they could not imagine going back to a conventional bridge again. The visual impression of this bridge environment was very tidy, well arranged with few buttons and handles and no local adaptations were seen. As a contrast to the visited passenger vessels where the crew was moving around the bridge to access equipment, the crew on these ships were seated in their main working position with the necessary equipment readily available. Some of the officers mentioned that having all equipment nearby actually made them feel like they were sitting too much during their working day. They were satisfied with the size and function of handles and buttons.

As opposed to the passenger vessel we visited this crew were very satisfied with touch screens, they were well functioning (they actually responded to touch) and had functions they found practical and useful, like being central control for dimming all screens, controlling all wipers and choosing which screen should show what.

Another example they found useful was that the information they needed for performing a checklist (that they do quite often) could be found in one single display, there was no need to search around in different menus to find the relevant information.

Some of the officers onboard had been involved in the design process, especially the last phases that included placement of equipment in the consoles. They also described having a good working relationship with the main equipment manufacturer regarding problems that had occurred when the equipment was newly installed.

There was alarms from different equipment on these bridges too, however, they seemed to be less frequent than on the retrofitted bridges and they were presented in one screen by the main working position which made it seemingly easy to find the source and act accordingly.

Although these officers were mainly positive, it does not mean this was a flawless system without room for improvement. However, the improvement points were of minor character and not concerning the overall bridge working environment. Examples of non-optimal solutions were equipment integrated in the main console was mainly from one supplier. Other necessary equipment could not be integrated due to lack of standardization; hence it was placed in a less central console. There were examples of displays where the illustrations were represented 180 degrees off relative to the view of the operator, or colors in displays making numbers very hard to read. The chairs in the main working positions did not accommodate sitting for several hours and were perceived as very uncomfortable.

The crew pointed out that this type of integrated consoles can make the crew more dependent on shore and as such be seen as a threat to the crew’s autonomy. E.g. when all lighting is controlled from the central bridge it is not possible for the onboard electrician to add an extra light somewhere. The new lights must be programmed into the bridge system by the manufacturer. This comes with a cost and thereby often is not prioritized.

3.2.1 *Designers view*

During the semi-structured interviews with two of the designers involved in developing this bridge they emphasized that research and knowledge about the actual context was a driver for their design. They had performed field research as well as having seafarers coming into their premises to test solutions during development. They experienced that the end-user often had other needs and preferences than they imagined themselves, hence it was important to involve the end-user at several stages during development. This type of research and development takes time and comes with a cost for a commercial actor. They encountered several challenges on the way, like regulations that did not accommodate integration of equipment. In their opinion, they sometimes had to compromise and make a less user-friendly solutions to get the equipment classified. Integration of equipment from several manufacturers is difficult due to the lack of standardization. Often customers require the opportunity to install equipment from several manufacturers, and the designers felt this often hampered the end result and consistency of user interfaces. In addition, they described the maritime sector as conservative where the interest and perceived need for user-centered design is low. The main driver in the sector is cost, not function. Although they were continuously working on finding suppliers that can deliver materials cheaper, it has been difficult to get a significant position in the market.

4. Discussion

4.1 *The dynamic development of a bridge*

The maritime domain seems to have been slower than other complex domains in applying human factors and ergonomics knowledge in design and development (Lützhöft et al. 2011).

There may be several reasons that combined lead to seemingly chaotic retrofitted bridges. With no holistic view of the bridge environment guiding placement of new equipment, the placement decisions will be determined by lack of space and focus on cost saving. Another contributor may be the designers and equipment manufacturers lack of insight or understanding of the working life on-board. Meck et al. (2009) found that designers had little concrete, detailed knowledge about the maritime context. They had different notions regarding ergonomic design, usability and feedback loops, as well as a having very different images of the navigator and his/hers role within the bridge system.

A ship bridge can be seen as a compromise between the ideas of the designers and the seamanship of the end-users. Often the situation is that the technical specialists develop equipment independent of what the seafarers see at useful and expedient for their daily effort on board. Instead, the designer has the actual customer in mind when they construct the instruments, namely the technical expert in a shipping company. These experts often have the same educational background and experience as the designer himself.

The heterogeneity of a ship bridge can also be related to running maintenance of the different instruments on board. When certain instruments are broken or destroyed, they need to be replaced by a device with the same functionality, not necessarily from the same brand or manufacturer. This may involve different interface and technical solutions such as a button may replace a handle or belong to a whole different design philosophy.

The interface between the seafarer and the ship bridge, is also characterized by a cacophony of alarms. All the instruments and devices come from different manufacturer and most of them have their own alarm. Often regulations require that every instrument have its own alarm. It can be a challenge for the officers on board the bridge to interpret and locate the source for the alarm.

Replacement or retrofitting of instruments due to new needs and requirements in the industry, also lead to variation in the design on board. For example, a stronger focus upon environmental issues and so-called *green speeding*, have led to new monitors of fuel consumption on board. We have witnessed such retrofitting of equipment due to new company policy and emphasis of energy savings. Often this new device is not fulfilling the usual routines and activities on board. For example, one of these monitors that were centrally placed in the console did not have dimming functionality, which is critical when the seafarers on the bridge should keep the night vision during night time. As one of the officers explained that this screen "was not made for being placed on a bridge".

4.1.1 *Implications for sensemaking*

This quotation sums up a large part of what the seafarers must handle in their work environment. Or as another officer put it "this probably functioned very well in the office" while showing us poorly functioning equipment claimed to have been tested and verified before being installed on board. Many of these poor solutions contradicts the seafarers common sense and enhances the impression that designers, shipping companies and regulators on shore do not understand what their job is about and what functions or not at sea.

It is important to notice that many of these problems may seem like annoying or impractical details, however as many seemingly small details pile up they create a demanding environment for sensemaking. Sensemaking is "focused on and by extracted cues" (Weick, 1995). In an environment cluttered with information presented in various ways it makes it challenging to extract the relevant cues for the task at hand. There are many examples where accidents have developed due to cues have not triggered sensemaking as (Maitlis and Christianson, 2014). Having an abundance of alarms going off, often with similar sound, despite of which instrument of which degree of seriousness the alarm warns about lay the groundwork for overlooking important cues.

What kind of interpretation a cue will trigger depends on the cognitive framework the individual person has, a framework developed based on factors like experience, education and identity. These frames will most likely differ between a designer and a seafarer. Developing an instrument with an alarm may seem like a salient cue with an obvious interpretation for a designer while being conceived differently by the seafarer. When the instrument is put in a context with many other instruments as well as motion, noise and long work hours, the cue may not be salient anymore.

To adapt to a variation of equipment, instruments and digital solutions are a central part of a maritime career. However, as many of the technical solutions do not provide the information actually needed and contradicts the seafarers' common sense they have to make adaptations to make every day work possible. It is not surprising that the result is equipment that "had not been used as expected by the regulators or equipment manufacturers" (MAIB, 2017) as we saw in the *Muros* case.

4.1.2 *Seamanship as adaptation*

Although the bridge environment may be a less than optimal work place, the seafarers manage to do their job through adaptations and tailoring, or "integration work". As Lützhöft and Nyce (2008) describe it is "a part of the seafarer culture to be able to 'handle anything', and thus when a burden is added, seafarers frequently adapt and handle it". It is necessary to be able to manage with what you have when you are out at sea far from the nearest harbor with the spare parts you need.

The sensemaking perspective emphasize that people not only passively experience and interpret their environment, they create the environment they make sense of, by being a part of the environment, by which cues they extract and by their actions. The very visible forms of adaptations and workarounds crew implement, pallets to stand on, covering up screens to dim them, marking of buttons and levers, may be seen as very salient ways of creating the environment they extract cues from. When their environment does not work, they actively create an environment that makes sense.

A phrase we often heard was "getting used to it", the officers described that a particular equipment was difficult to use at first, "but now I'm used to it". This phrase was used both by the officers working on the old, retrofitted bridges, and the officers on the offshore supply ships. One of the latter had previous experience from an old conventional bridge with a lot of buttons and things out of order. He explained that while he was working there, he was used to the circumstances and didn't think much of it. When he started working on the new integrated bridge he did not like the touch screens at first, but after getting used to them he now thought it was the best solution. It should be noted that the adaptation element can be seen as a bias to be taken into account when using end users' opinions in evaluation of design.

Also, what the seafarers think about their working environment seemed to be relative. One of the old bridges had been through a refurbishment a few years back, so despite pointing out several problematic issues on the bridge the seafarers were rather positive. One possible explanation for this can be linked to the fact that "it used to be worse" and thus just a matter of relative improvement. The fact that it now is relatively better makes the situation perceived as positive, despite the obvious room for overall improvement.

4.2 *Seamanship as part of bridge development*

Although it seems the majority of ship bridges do not accommodate the end-user perspective there are exceptions, as the field trip to the two offshore supply vessel showed. The designers of this bridge emphasised and took pride in the end-user involvement in their design development. The end-user involvement implies the design try to take into account and support the real work practices and may be seen as involving seamanship in the design. The bridges seemed to be successful due to factors like decluttering of the surfaces, meaning getting rid of irrelevant cues and letting relevant cues become more salient. Also, having the most important information around the main working position was perceived as practical and helpful by the officers. Information was presented in a way that resonated with seafarers' common sense, this can be seen as facilitating interpretation of the cues in a manner consistent with design intentions.

There was no local adaptations observed on these bridges and the officers expressed being very satisfied with their work environment. This does not mean the perfect bridge solution has been invented, but that some of the main ergonomic issues had been resolved in a way accepted by the seafarers.

4.1.2 *Why is user-centered design not widespread in the maritime sector?*

Currently there seem to be a slow development where integrated or unified bridge systems are being developed by several maritime equipment suppliers. A bridge design truly based on research and involvement of end-user comes with a cost, the iterative nature of user-centered design is time-consuming. This is a challenge for a commercial actor competing in a market. The designers we interviewed experienced that cost, not function was the major driver in the maritime industry.

In addition, there are many factors that influence design. Our informants found that regulations sometimes constrained the designer's freedom to choose what they thought were the optimal solution. In order to comply with regulations and achieve classification they had to compromise and sometimes end up with less user-friendly interfaces. Other times customers wanted the possibility to install equipment from other manufacturers that was not compatible with their bridge solution. To accommodate customer requirements, they would have to make adjustments that would result in a less user-friendly interface.

The designers had the impression that the maritime industry in general has little interest in human factors and design, or knowledge about how these disciplines relates to safety. There is no need to change something that seems to be working ok. As Meck (2009) put it «the conviction that usability and ergonomics may result in long term success and competitive advantages has not yet struck roots with all parties involved».

An important part of this picture is that the maritime industry is rather conservative. A lot of the ship building processes, including the procurement of ship bridges, might be based on old and often informal social network, in addition with already established formal contracts between the companies.

Also, the status of the seafarer, is part of this backdrop. The seafarer has always been holding a relatively low position in society, since he has been away and not taking part in ordinary societal lives. He has been out at the open sea, unreachable and often for several months at the time. In contrast to these peripheral professionals, we have the land-based positions, who are perceived more predictable and trustworthy.

5. Conclusion

Seamanship, sensemaking and technology influence each other. New digital solutions may contribute to a more demanding everyday work on-board, were seamanship includes more technical skills and competence to meet the professional requirements in the industry.

This situation of increasing digitalization may gradually change the content of what is referred to as seamanship; other skills and qualifications may be chosen in the recruitment and training efforts in the future.

Nevertheless, independent of what is going on on-board regarding skills and experiences, some fundamental characteristics of this profession remain the same. The seafarer is still onboard a boat at sea, in a complex, noisy, hierarchical and dynamic environment. The weather may be forecasted on screens but are still experienced and must be handled “for real”. One of the officers we talked to explained good seamanship as working *with* the weather as opposed to *against* the weather. Sensemaking on-board combines making sense of a huge amount of information presented on screens as well as more embodied sensemaking from looking out the window, seeing and hearing the weather and feeling the ships movements (Danielsen, 2018).

Also, a huge challenge for the people on board, is all the water that surrounds the vessels. A lack of online solutions, due to a scarcity of satellites and/or very expensive technical possibilities, give rise to a professional ideal of being self-sufficient when it comes to a long range of services. To be excellent at troubleshooting is not only an ideal and thus a significant part of seamanship, but a necessity. No one can assist you when you are out on the seven seas.

It is evident that involving seamanship in bridge design can contribute to reduce the gap between technology-as-designed and technology-as-used, and thereby contributing to improved safety at sea. However, seafarers have limited opportunity to provide feedback or influence the bridge design. There seem to be a lack of “structural or organizational systems in place that would allow for a systematic closed feedback loop between users and designers” (Meck 2009). Lurås and Nordby (2015) suggested that designers should develop “sea sense” by performing field studies to be able to make good design judgements. Probably a combination of efforts needs to be considered, from including Human Factors and Human Centered Design knowledge into maritime engineering education (Abeysiriwardahne 2016) to a more general improved understanding between the classic design engineering discipline and the human factors discipline (Petersen 2014).

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