Abstract

In this paper we show that safety analysis using the STAMP causation model is limited in the extent to which it appreciates complex dynamics of safety. When the STAMP is applied as management tool, controls may be introduced too soon in the analysis since it is necessary to understand emergent behaviour first. Emergent behaviour can be studied through organizational ethnography in parallel development with an agent-based model, as illustrated in a case study of airport ground handling services. Based on ethnographic research and theories from psychology and social sciences, we developed an agent model that showed why repeated attempts at managerial control to improve employees’ safety compliance were not durable. The insights obtained through the case study attained to move management ideas about what control means towards creating smarter design and communication processes that involve the work force.

Keywords: STAMP; organizational ethnography; agent modelling; safety management; aviation.

1. Introduction

Leveson’s STAMP (Systems Theoretic Accident Model and Process) promises to offer an alternative view on safety from traditional rule-based behavioural approaches [1]. It is framed as a ‘New View’ [2], a ‘model 2’ [3], or even a whole ‘new paradigm’ to safety [1]. STAMP explicates a model of the organization where safety is a control problem. Complex and emergent patterns in working processes are controlled by hierarchies of controlling units, e.g.
management levels. These function by developing an adequate model of the process and algorithms to control the process. STAMP is ‘new’ or ‘model 2’ in the sense that it explains why safety should be a matter of continuous adjustment with thorough understanding of the complex interactions between various aspects of the work processes and technologies.

‘Old’ models such as the Swiss Cheese Model (SCM) simplify accidents as the outcome of chains of events that must be stopped by series of barriers [4]. The barriers are like slices of Swiss cheese, containing holes through which some unsafe actions may inadvertently pass through. Therefore, this theory implies that organizations should find out what kind of failure modes and accident paths exist and install multiple barriers in its way, such as physical redundancy or behavioural barriers (e.g., Standard Operating Procedures). Methods that use this way of thinking can be subsumed under the label reliability engineering.

A growing number of researchers believes that at higher levels of safety and in more technologically complex contexts, safety is better represented in terms of complex dynamics, rather than SCM’s linear sequences of events [3, 5]. If accidents are complex emergent phenomena, then the rationale for designing safety nets in terms of preventing dangerous linear sequences of events is flawed. It is not possible to predict all failure modes and accident paths because safety nets may interact, fail to work as intended and produce new, unknown dangers [1].

Because linear reliability engineering models like the SCM have become part of the ‘working theories’ of safety management [6], also in contexts where this might not work, managers’ and regulators’ commitment to them may become ‘bureaucratic’ [7]. Working theories are internalized ideas and experiences that professionals, such as managers, use to understand problems and act in them. In this case, as the current literature suggests, managers may sometimes be wrongly advised to think about safety management as a chain of events issue. While they do, this may lead to conflict between managers and workers because the latter then come to view safety as a senseless burden [3]. The rules may not seem to be about safety but about covering responsibilities. The motives for introducing safety measures may be questioned and the designers of new and improved safety systems and procedures deeply distrusted.

The STAMP model embodies a fundamentally new approach to accidents and safety because it does acknowledge the complex interactions that contribute to accidents, and provides a way to analyse this complexity. STAMP could also have promising prospects as a working theory of safety management [8], as it may help deriving more sensible safety rules and procedures. Thus, STAMP may alleviate management-work floor conflicts about symbolic or bureaucratic safety rules.

In this paper, however, we argue that as a working theory for management, STAMP should not be seen as a whole new approach to safety. While STAMP is in many respects a significant improvement from older linear accident models, it has limitations as an organizational management theory. In some ways STAMP continues to encourage top-down thinking about management, because it is not intended to represent the behaviour of people. It simply places control on behaviour without understanding its driving forces, and does not count for the complexities that workers face and the contributions that they (could) make to safety. Therefore, STAMP to some extent fails to capture the ‘new’ view where safety is approached positively, in the sense that workers’ input to safety are fully appreciated [9].

We substantiate this point of view with a case study in an airline ground safety department that was struggling with poor management-work floor relations as it attempted to implement safety procedures and systems. STAMP was used to identify the weak spots in management control and communication, with the aim to formulate actionable changes in management and improve the situation. We found that STAMP created some insights but did not help providing an actionable analysis of the situation, because it did not help to understand how the sour relations had arisen. In the same organization we also conducted research using organizational ethnography and agent modelling, both providing some promising insights and courses of action.

Therefore, in order to achieve a truly ‘new’ view, we recommend the use of complementary approaches to STAMP that attempt to capture the social dynamics and creativity that emerges bottom-up. We propose a process by which knowledge from relevant disciplines can be accessed and used in an empirical analysis of a particular organization. There is a large, untapped body of work from socio-technical systems modelling, social psychology, sociology, anthropology and organizational sciences that could refine working theories of safety managers, as well as the field of safety science. This could help analysts and managers understand the emergent behaviour of systems, before they introduce control. In this paper we show how those two methodologies can be applied in tandem to overcome the limitations of the STAMP approach.
First, we introduce organizational ethnography as a way to derive an in-depth, and more power-sensitive account describing the origin and sustainment of certain patterns and behaviours. This is an open-ended process that begins with immersing oneself in various sub-cultures of the organization, conducting in-depth observations, interviews and document analyses, before theorizing what might be going on. In the final phases, from a holistic frame of mind, the researcher may develop interventions and discuss those with members of the different sub-cultures.

Second, we introduce agent based modelling and simulation as a method to zoom in on specific parameters that might be usefully controlled in terms of a control loop suggested by STAMP. This method integrates theories of behaviour early in the analysis to create a model. This model is then instantiated in simulations, predicting emergent patterns that may be validated using alternative datasets of the same situations that were observed. The predictions can also be used to design interventions, and further validation or adaptation of the model may occur by monitoring the path and outcome of interventions.

Thus, the safety analysis and management methodology can explain how new ideas and frustrations emerge that are seeking to be heard, and how these inputs are diffused, integrated, or locked out of management decision making.

<table>
<thead>
<tr>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
</tr>
<tr>
<td>FOD</td>
</tr>
<tr>
<td>LOSA</td>
</tr>
<tr>
<td>OE</td>
</tr>
<tr>
<td>SCM</td>
</tr>
<tr>
<td>STAMP</td>
</tr>
<tr>
<td>STPA</td>
</tr>
</tbody>
</table>

2. STAMP, organizational ethnography and agent modelling

STAMP is an accident causation model that reduces safety to a control problem [1]. The system consists of the processes that need to be controlled, controllers who have models representing the process and a control algorithm, sensors that provide data on states of processes, and actuators that exert control on the processes. One may stack controllers upon one another; the agent controlled by a higher hierarchy is essentially seen as a process that can be controlled by the same principles. The controlling unit determines the set-point at which level the controlled process should run. Leveson [1] claims that in this way STAMP can be used to analyse accidents, design socio-technical systems, and manage safety in organizations.

When applied to organizational management, Leveson introduced the Systems Theoretic Process Analysis (STPA) to design good organizational controls or manage their functioning real-time. The STPA cycle contains 1) identifying the possible system states out of intended control constraints; 2) finding out how the control architecture could fail to control the system in these instances. In both these steps STAMP is used as tool to depict how system elements interact and what hazards could emerge. This may lead to a redesign of the controls, such as updating the control algorithm or closing a control loop by ensuring that the process provides information.

Organizational ethnography is the anthropological method applied to organizations, viewing any organization as a group that develops a culture [10, 11]. The main insight imported in organizational sciences from anthropology is that culture is highly complex [12] and that prediction is almost impossible, in part because people are not neutral devices since agency and management models aim at controlling them. Management systems are political because they are built on assumptions that work out to grant some more power and privileges than others [13]. Systems can also be politicizing when people learn how the system works and use them to their advantage. In social science discourse this is referred as agency [14], meaning people have the ability to reflect on what is happening to them, form goals, and make decisions to achieve those goals. They have various tools at their disposal, such as humour and ridicule, to distance themselves from management control while also endorsing it [15]. This may render managerial control ambiguous. The solution generally proposed by organizational ethnographers is to immerse oneself in the organization with as little preconception as possible, or at least making them as explicit as possible, and thoroughly observe what
is really going on [16]. The ethnographer remains sensitive to the fact that various groups may have an interests to be represented in certain ways. All social skills of the ethnographer are used to establish rapport and engage with people, while keeping some intellectual distance [17].

Given this interest in understanding how agency works in safety management, it makes sense to apply Agent Modelling (AM). While Organizational Ethnography (OE) allows one to gather large amounts of qualitative data and inductively work towards the most appropriate framework for the dynamics observed in the given setting, AM can focus on a specific work process and make more quantitative predictions. In particular, in this research we modelled multi-agent systems. These systems consist of human and/or technological (in this case, only human) agents that have the capacity to form goals and make decisions, that influence one another, and that may participate in certain processes. Modelling complex agent systems is interesting because it allows one to understand how nonlinear patterns emerge from many local interactions. The method uses empirical data and relevant theories to create an agent model, which can be programmed in several different platforms (e.g., Matlab). Patterns of interest, such as varying level of compliance with safety procedures over time, are not hard-coded but emerge from the simulations. By matching the simulation data to empirical data, the model can be validated. Sensitivity analysis can be performed to explain why the patterns occur and make predictions.

The two methodologies are also complementary, as Mols et al. [18] showed. While ethnography allows for an open gaze and holistic understanding of dynamics in an organization, formal modelling forces much more precise descriptions and explanatory frameworks that make the overall interpretation more sound. Both methodologies support a social constructionist view of organizations and social order, meaning that attention is paid to the messiness and intractability that people experience by resisting oversimplification of those experienced realities.

3. Methodology

We applied STAMP to a safety management problem where occupational safety emerged as the main issue of concern, a domain that Leveson [1] also suggests could be usefully managed with STAMP. The case study was an airline ground service provider experiencing difficulties to improve safety compliance of its work force. Ground service work—concerned with (un)docking, (dis)embarking and (un)loading of aircraft—is traditionally dangerous work, and serious injuries and deaths have not been uncommon [19]. In recent years, both damage to aircraft on the ground as well as harm to ground personnel have escalated, and safety programs were setup to improve safety. In the organization where we conducted our research, Line Oriented Safety Audits (LOSA) were introduced along with stricter rules and procedures, and attempts to change the safety culture. LOSA observations on the platform checked actual practices against written procedures and communicated what systematic deviations occurred, so that managers could enforce better compliance with these points [20].

This method of working with LOSA seemed perfectly in tune with viewing the employees as the controlled process, and the extensive hierarchy of managers as the control architecture consisting of many control loops. The process was complex, because when managers would start enforcing compliance on one point, compliance would relax on another. The organization consists of several departments working on different locations and there are many interacting processes and coordination issues. Therefore, STAMP seemed suitable for analysing the problem. STAMP application in other cases in the same domain were proved successful [21].

In this case, however, STAMP did not provide an adequate framework to analyse how and where management control was failing. There were many control loops that could be seen as failing and therefore explain how this situation had come about. The managers themselves reported many employees worked at the company for over 20 years, forming tight friendship ties and making it impossible for someone to interfere and change their behaviour. The conditions of the company, however, also did not allow refreshing the work force or shifting team composition more. Memos were ineffective: people did not read them and felt managers did not know what they were talking about. Safety reporting was low; it seemed that people were not appreciating its importance.

The solution, from the STAMP analysis, appeared to be that managers should be more present at the work floor. Yet, it was not clear what managers should do besides telling people to stick to rules, the latter being really disregarded since those were devised by managers whose expertise was doubt. The data for LOSA suggested no difference between managers whose commitment to improving safety was expressed through more visibility at the platform, and those whose commitment was less visible. An adequate understanding of the work processes and a full consideration of the reflection and skills by which ground service employees performed their work were missing.

To gain a better perspective on how hazards are controlled in real world ground service work settings, we conducted
organizational ethnography and agent modelling. Organizational ethnography allows for a more up-close look at what is happening. With agent modelling, one may create a model that explicitly incorporates complexity of the work processes and the way team members influence each other.

In this case we conducted organizational ethnography and agent modelling simultaneously for two years. The initial team in the first year consisted of an ethnographer, an agent modeller, and a STAMP researcher, plus a supervisor for each of the fieldworkers. After this year of fieldwork, we had an elaborate description of the control structure, but still insufficient understanding of how unwanted behaviours — of both managers and employees — arose. Lacking satisfying results, we continued for a second year with only ethnography and agent modelling. The agent modelling sub-team selected a newly designed procedure for the aircraft turnaround process to instantiate the model, allowing precise predictions that could be validated by LOSA data. A newly appointed organizational ethnographer meanwhile observed management meetings in-depth as well as work performance at multiple platforms. The aim was to understand how the joint team’s insights could be translated to useful advice in view of the differentiation between work force and management. The results and suggestions presented at the end of the second year triggered discussions and were endorsed by members of management, suggesting that we had arrived at a proper analysis and actionable suggestions.

The resulting, iterative investigation process can be described in three steps, as visualized in Fig.1. First, the agent modelling (AM) and organizational ethnography (OE) teams jointly discussed the situation of the organization in question as presented by them by the management. They used the STAMP framework to create a first impression of the hazardous processes that exist and that are problematic, and the control architecture that allows the hazards to occur. In this stage, both teams tapped into their respective disciplinary knowledge and formulate ideas about what may be going on in the organization that might fall out of the STAMP framework and for which management may have a blind spot. This lead to a set of qualitative, open-ended questions for fieldwork.

Second, members of the AM and OE teams conducted observations and interviews at the work field, and analysed organizational schematics, charts, safety data, written communications, and procedures. The team members observed how safety-critical work was done and how members interacted with each other. They talked with members of the work force, management, and administration, and collected war stories or anecdotes that were told to express difficult dilemmas and ways of resolving them. These data were recorded as field notes, interview recordings and transcripts. The fieldworkers communicated amongst them as means to develop an idea of what were the significant agents and processes, and revisited relevant literature to dig up interesting concepts and theories.

The OE used the data to develop a framework to characterize the dynamics of the overall culture, while the AM created a conceptual model of agents, their relations and influences, and local processes they were engaged in.

Fig. 1. Research process.
Connecting to developments in the organization, the AM selected a significant process or practice to create the precise, formal model. The process, such as the implementation of the new turnaround procedure, allowed for longitudinal data gathering. The data were qualitative and/or quantitative, taken from existing databases and/or by continuing to monitor developments. The AM and OE teams regularly met to discuss their respective conceptual model and framework, so that they were able to integrate their knowledge and confirm they understood at some level what the other team was doing.

When the teams felt they had a sense of what is going on, they moved to step three, separated into two parallel tasks. The OE characterized the dilemmas experienced by members of the organization by writing a thick description. This involved picking out telling anecdotes or physical details, interpreting what they signified for members of the organization, and showing how those contributed to specific behavioural dynamics as well as a more global texture of the culture. The way in which what it means to work safely may differ in different sub-cultures of an organization, is an example of a more global texture; a detailed example of this can be found in Atak and Kingma [22]. Focusing on more a detailed work process, the AM finished the formal model and instantiated it to run simulations that should reveal patterns matching the longitudinal data. By performing sensitivity analysis, tweaking specific parameters and running statistical analyses over the results, the AM team developed predictions about how emergent patterns came about. This method is described in more detail by Sharanskykh and Haest [23].

With the interpretations of the simulations and the qualitative description and framework, the team reverted to step 1. They got together with members of the organization to revisit their ideas about how dangers came about and how they may be effectively controlled. This resulted in suggestions for interventions and design recommendations as well as leading to new questions for field work. Multiple iterations of this process may be necessary to arrive at a satisfying result.

4. Results and discussion

The research applying OE and AM showed that control had to be re-thought as a matter of creating smarter and more bottom-up processes for procedure design and employee involvement, also suggesting some practical courses of action. This replaced the idea inspired by the STAMP analysis that a control loop had to be closed, interpreted as that management should be more visible and enforce top-down designed procedures and rules.

The OE results showed that employees who distrusted the design process of new procedures and the commitment of management to safety, had a point, even though managers were very active with safety. The problem was not that anyone was lazy or did not do their job properly, but rather that managers had a tendency to stick to their office and domain too much. Different units were given much leeway in how they wanted to carry out safety policies, and this together with their activity shifting emphasis from one domain to the other actually frustrated personnel and made management appear inconsistent. There was little communication between units, which could cause coordination problems. It turned out that employees did not file safety reports, because when the issue they reported was not urgent, there was no response from the safety department. This made them believe that their reports were not being used, which was actually untrue; all reports were gathered, analysed, and discussed in regular Risk Assessment Meetings.

The result was that safety managers thought that employees did not care about the work and about safety, and that employees thought that managers did not really care. Employees felt that managers held double standards with respect to their work and safety: if they complied with procedures, they could be reprimanded for being slow, and if they worked around procedures to be on time, they could be reprimanded for violating procedures. Most worryingly, some new procedures actually carried more danger than the old ways of working that were now seen as deviant and dangerous by management. It had been forbidden, for example, to use the baggage high loader as a way to move personnel up to the aircraft baggage compartments; instead, a ladder should be used. The narrow, high ladder however was much more dangerous than the high loader—if properly used.

It was then possible to understand why personnel disqualified management as a whole and distrusted and ignored procedural instructions. Given these issues, heightened by the limited interaction between managers and work floor, it seemed plausible that polarization could easily occur as a consequence of common group dynamics such as those described by social identity theory [24]. The out-group—management—is reified and simplified and generally less trusted, while the reverse is true for the in-group. Similarly, management members appeared to have reified their image of the work force. There were some good attempts at promoting safety that could have mitigated these problems somewhat, but these were not used to their full potential. Safety delegates were appointed to promote safety, but they were not used to communicate across units. The development of new procedures often involved members of the work
force to ensure the procedure incorporated their knowledge and experience, yet this was usually done with a particular group whose representativeness was questioned.

The AM research gave further insight into how and why control as exerted by using the LOSA data to enforce compliance on specific points, was ineffective, as well as how compliance could be improved. The analysis zoomed in on an adapted procedure for docking aircraft that arrived at the gate. Before aircraft are guided to the gate, the platform is checked for debris and obstacles. After the aircraft is parked in position, blocks are placed at the landing gears and pylons around the engine areas. Before the gate attaches to the plane, someone checks if it is clear and gives a thumbs-up to the operator of the moving gate. The aircraft is connected with the ground power unit and the door seals are inspected. In this sequence, the initial Foreign Object Damage/Debris (FOD) check showed up in LOSA records as relatively frequently being skipped, probably in order to save time. Management had attempted to change this by providing information and emphasizing the FOD check for some time, which improved compliance; but when information ceased, compliance declined. The new procedure included an explicit role division connected to particular tasks, determined by the team leader during a short briefing just before commencing the entire process.

The AM team developed a formal agent model that explained the old situation as well as tentatively predicted with some accuracy the changed situation. The model was created using several theories. Motivational models of human behaviour used were self-determination theory [25] and Maslow’s [26] hierarchy of needs, including a distinction between intuitive, habitual reasoning and conscious, rational reasoning [27]. A learning model explained how new information is processed by way of social contagion, describing how new norms arise and spread in teams. Work demand and pressure were modelled as varying over time. Management control was modelled as the likelihood that team members would be reprimanded when intending to skip the FOD check. The change from the old to the new procedure was instantiated by adjusting the values for probabilities of reprimands by managers and team members and the speed of social contagion in direct (e.g. talking) or indirect (e.g. observing someone do something) communication. In the new procedure with explicit coordination (i.e. task divisions and roles), for example, the probability of reprimand from team members was estimated to be above zero, while it was set at zero in the old, implicit coordination procedure. Further detail on the model can be found in [23].

The simulations of the implicit coordination scenario reproduced the pattern described above where temporary attention by management to the FOD check led to temporary increase in compliance. The explicit coordination case predicted that team members would develop a team norm to complete the FOD check before allowing the aircraft to park, and that reduced control from management would not quickly result in reduced compliance. These results were also observed in practice [23]. The sensitivity analysis furthermore revealed that management control was a relatively ineffective method to establish compliance. Addressing agents’ needs to understand why an action needs to be performed a certain way, came out as more influential. Responding to team member norms also became an important factor. Because members have shifted in this scenario to a more conscious, rational way of reasoning, these norms then become ingrained and compliance remains high, also after management relaxes control.

One manager, upon being presented these findings, expressed being humbled and realizing that he felt he might have over-estimated his influence over the process, understanding the relatively low influence of direct management control. On the other hand, once the ethnographic findings and recommendations were presented, several managers and team leaders who had in some way been involved in the research project were also enthused by realizing what influence they might have. The ethnography team members suggested that the organization form safety teams consisting of members of every level of the organization, especially the very lowest rank, and create a thoroughly bottom-up procedural design process. This resonated so strongly with the sentiments of those present at the presentation meeting that they instantly began brainstorming about ways to make it happen. They identified some potential obstacles—how does one select people outside the circle of ‘usual suspects’ of people involved in safety initiatives—and came up with solutions—asking leaders close to the work floor to select them. They expressed commitment to essentially turn around the design process of new procedures in such a way that management would primarily take expertise from the work floor for the details of the procedure, and then check against regulation, instead of deriving procedures from new regulations.

5. Conclusions and suggestions

Replacing former working theories such as the Swiss Cheese Model, STAMP is meant to capture and control better the complex dynamics of safety. Despite the potential of the overall systems theoretic approach, where safety is taken
as an emergent phenomenon of complex socio-technical systems, there are some problematic simplifications in the STAMP methodology. We argue that when STAMP is applied as a management tool, control is introduced too soon in the analysis cycle, and that it is necessary to understand emergent behaviour first.

To complement STAMP, emergent behaviour can be studied through organizational ethnography in parallel with the development of an agent-based model. Organizational ethnography is a processual (i.e. describing patterns over time), qualitative analysis of work practices and social relations at multiple levels of an organization. Agent models represent people and technology, as required, that perform actions, make decisions with some degree of autonomy, and exert influence on each other. By properly integrating relevant theories of human behaviour as well as data on local practices and relations, the model simulations should reproduce the emergent patterns described by the processual qualitative analysis. The model can be further validated with separate datasets of the old situation, or of new developments unfolding as interventions take place. Sensitivity analysis of key parameters allows analysts and managers to pin-point and test the most efficient measures of control.

In deriving an agent model from an ethnographic account, information and nuance is lost and one should not see the agent system as a definitive description; yet it offers courses of action when STAMP is applied at this point. Sensitivity analysis of key parameters in the agent model that specify relevant agent interactions and influences, allow analysts and managers to pin-point the most efficient measures of control. Control loops are thus more contingently and smartly situated in emergent behaviours of the system.

Thus, we suggest that STAMP is complemented with OE and AM in order to achieve a complete ‘new view’ in safety analysis and management. The particular findings in this case, such as the need for explaining the reasons behind instructions, expressing worker autonomy in the way procedures are designed, and involving workers in the design process, are likely to be more generally applicable factors in establishing a ‘new view’ towards safety analysis and management. In this view, (safety) management is a two-way process where analysts and managers are curious enough to understand the human contribution made on the work floor, before they introduce control. Exercising control then becomes a matter of establishing a communicative rationality and aligning organizational interests such that work gets done in a way that is acceptable to all those involved.

Challenges that our approach throw up include the access to organizations and the resources and time needed to complete the analysis. Ethnographic research requires access to sites where activities of interest occur. Since at the outset it is often not yet clear what will turn out to be interesting, this requires a strong vote of confidence and flexibility from organizational officials, especially given the sensitive nature of safety-related questions. Ethnography can be very time-intensive, which may press the resources available to an investigative team. Ethnographers need time to become part of a group and get passed the sometimes subtle facades that organizational members tend to put up in any context [28], and especially in relation to safety [22]. The creation of a detailed agent model, integrating several types of data and theory, can also be a lengthy process. Further potential challenges exist in forming an interdisciplinary research team and establishing a collaboration that bridges the different knowledge and scientific norms of the two disciplines.

The suggestion in this paper is to form teams consisting of at least one expert trained in agent modelling and one expert trained in organizational ethnography, if both are also proficient in safety analysis and management theories such as STAMP. If not, an additional member can be added with expertise on this domain; the agent modelling expert is likely to be from an engineering or computer science domain, and the ethnographer from social sciences. In our project we worked with fieldworkers and supervisors of each domain. We have addressed the challenges of interdisciplinary research, but a complementary approach such as advocated here requires a genuine interest and some knowledge overlap across fields. The project may usefully adopt the systems theoretic ideas about viewing safety as a control problem, as STAMP does, yet not be naïve about how the actual control architecture functions, given the complexity of human interaction.

Acknowledgements

The authors would like to thank all anonymous research participants, the STAMP researcher Jisvy van Zoelen, the ethnographers Romy Heimering and Joyce Bakker, and the agent systems modeller Rob Haest, for their contributions to this work.
References