CRISIS MANAGEMENT EVALUATION: FORMALISATION & ANALYSIS OF COMMUNICATION DURING FIRE INCIDENT IN AMSTERDAM AIRPORT TRAIN TUNNEL

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ABSTRACT

Communication and inter-organizational coordination in crisis management are of uttermost important for all processes and can lead to fast and effective averting or ending of a crisis situation. In this paper, a real world incident of a fire in the Amsterdam Airport Schiphol train tunnel was formalised, based on a public inquiry report, and subsequently, the emergency response to the incident was analysed by means of automatic property checking. It is shown how this approach is a convenient and effective manner to analyse communication and coordination practices in crisis management and to evaluate what went wrong, where and when.

INTRODUCTION

Fast and effective emergency response is crucial for public safety in critical areas such as tunnels, but the coordination to realise this often fails. In the rare event of a crisis, various parties must be prepared to react in a timely, coordinated manner, which often does not occur. Crisis coordination problems are an international phenomenon. The catastrophic effects of Hurricane Katrina, that hit New Orleans in 2005, showed how fragmented distribution of new information impaired speedy response and how ineffective communication between disciplines incapacitated coherent decision making (Cooper and Block 2006; Comfort 2007). The disaster Hurricane Katrina became iconic because of its scale, but similar problems with crisis coordination occurred during smaller incidents. For example, the crash of a Turkish Airline Boeing 737-800 near Schiphol Amsterdam on 25 February 2009, revealed the problematic communication routines of the first responders (IOOV 2009). These cases illustrate that improved coordination strategies are needed. In the Netherlands, like in other countries, emergency services – fire fighters, police and medical services – are attempting to learn from failures in previous experience during incidents and accidents.

Rigid command and control structures currently in place cannot adapt quickly enough to the unpredictable events as they unfold. Research suggests that the military concept of Network-Centric Capabilities (NCC) could fulfil this need (Houghton et al. 2008; Moynihan 2009; Von Lubitz et al. 2008). These capabilities authorize first responders to decide faster, supported by communication systems that enable shared situational awareness (Gorman et al. 2006; Yang et al. 2009). In order to implement NCC and improve emergency response, coordination processes during crises must be better understood. Methods to analyse crises, however, are costly and time intensive.

This paper shows how a formal analysis, using automatic property checking, can provide a more efficient and practical method to study crisis coordination processes (e.g. Hoogendoorn et al. 2009). In general, empirical data is formalised in so called traces. These traces can be analysed automatically by checking if certain dynamic properties hold in the traces, via a software tool based on the Temporal Trace Language (Bosse et al. 2009). The case to illustrate this method is a dangerous fire incident that occurred on July 2nd 2009 in the train tunnel and underground train station of Amsterdam Airport Schiphol. Different modalities of crisis management could be studied by formal analysis, such as the beliefs and intentions of those involved, as is done in (Bosse et al. 2011). The current research focuses on actions and communications, because by using data from a public inquiry report (IVW and IOOV, 2009), actions and communications are the most accessible and they are essential to the emergency response problem. Others have focussed on the human reasoning process during incident management (Bosse et al. 2008) or on aviation incidents (Bosse and Mogles 2012). Communications relay information that must be shared timely and spread coherently in the overall network of involved parties. Furthermore, they are more reliable than beliefs and intentions, which are not clearly stated in the report.

Our research question is: How can automatic property checking be used in the formal analysis of coordination problems occurring in emergency response during crises? This question is answered by

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showing how our method indicates the measure of success of several key coordination features. These features refer to the time of response, disciplinary boundaries, and the quality of information sharing in the overall network. Emergency response must be effective in a short, specified period of time after the fire hazard arises. Information must be spread quickly across disciplinary boundaries to facilitate a common operational picture. Overall, the information network must support quick and effective decision making, where for example urgent requests prompt quick and adequate reactions.

The paper proceeds as follows. In Section 2, the Schiphol train tunnel fire case is briefly described on the basis of the public inquiry report (IVW and IOOV 2009). Section 3 details the formalisation process and the resulting formal trace. Section 4 explains the automatic property checking and its results. In the final section, we conclude what value this method has in the field of crisis management research.

SCHIPHOL TUNNEL FIRE

On July 2nd, 2009, an incident took place in the Schiphol train tunnel and station. Around 5:25 PM, dirt collecting in an open case just next to a railway track containing electrical wires began to smoulder, due to a spark released by the braking wheels of a passing train. The case was located in one of the two adjacent tubes on the side of Amsterdam city. Alarm calls went to the Schiphol Coordination Centre that was quick to mobilize airport fire and medical services. The remotely operating Railway Traffic Controller (RTC) also received reports about smoke from train conductors passing through the station, but was hesitant to declare an emergency. When signals and switches began to malfunction, three trains halted in the tunnel tube where the fire was, because of standard procedures in case of such malfunctions. A ‘disturbance’ emergency scenario was declared by the RTC and his back office. Coordination between the railway and emergency services occurred mostly through the railway Emergency Operations Coordinator (EOC) and the Airport Fire Officer (AFO). As a result of miscommunication, the three trains in the tunnel had to hold for over thirty minutes with increasingly anxious passengers (IVW and IOOV 2009). The AFO asked the regional dispatch room to relay to the Emergency Operations Director (EOD) a request to drive the trains out of the tunnel. This would create a safe space for the fire brigade, holding on the station’s platform, to enter the tunnel and find the fire. Instead, the EOD asked the RTC to hold the trains where they were, because he thought the fire fighters were already in the tunnel. The exploring fire fighter crews, who could not find the origin of the fire, were surprised to find the trains standing in the tunnel. They asked for their immediate departure at 6:00 PM through their commanding AFO. He relayed this to the EOC, who was initially unable to pass the order through to the RTC, as he was on the phone with the technical department and had no additional phone lines. After receiving the message, starting at 6:05 PM the RTC ordered the trains out one by one, which took 15 minutes to complete. The fire had already died out by itself, and had not posed a real threat. Yet it had taken far longer than the critical 15 minutes to secure a safe evacuation of the passengers *or* to find and control the fire.

FORMALISATION OF CR ISIS M ANAGEMENT COMMUNICATION

In this section, the process of formalising the available data is addressed. First, the goal and content of the report, from which the data on the calamity in the Schiphol tunnel was extracted, is discussed. Then, the formalisation process and the resulting formal trace of the course of events are described.

The Public Inquiry Report

The public inquiry report on the calamity in the Schiphol tunnel (IVW and IOOV 2009) served as a basis for the analysis of the coordination problems during the emergency response. The investigation is reported for a dual reason: to inform the citizenry on the response to incidents in the public domain, and to advise organisations on measures to prevent similar incidents in the future.

Time	Dutch Railways	ProRail	Emergency Services	Other
17:40		Trdl meldt problemen aan Backoffice ProRail. Trdl besluit gestrande treinen in tunnel aan Amsterdamse zijde terug te sturen. Backoffice ProRail zorgt voor verdere alarmering instanties en hulpdiensten.		RC meldt incident aan MICK. RC meldt incident aan Kmar, AAS Havendienst, AAS DMS en AAS Operations manager.
17:41	Medewerker NS Reizigers meldt brand aan brandweer.		TAS 341 van Post Sloten uitgerukt.	Persoon op perron (medewerker NS Reizigers?) meldt brand aan brandweer via Veiligheidscentrale
17:42	Mcn tr 2169 overlegt met Trdl i.v.m. gedoofd sein.	Trdl geeft mcn tr 2169 opdracht te blijven staan.		KMar en BHV AAS besluiten tot ontruiming alle perrons Schiphol.

Figure 1: Fragment of the Chronology of Events in the IVW & IOOV Report (IVW and IOOV, 2009).

The report consists of several parts. First, factual information on the location, cause and risks of the fire incident is provided. For example, an estimation of the number of passengers that were stuck in the tunnel is provided, and the extent to which the Schiphol train tunnel meets the safety standards is assessed. In addition, an overview of the involved organisations and services and their responsibilities is included, together with a brief description of relevant procedures and protocols. Second, the course of events is described from different perspectives, namely from the perspective of ProRail, the Dutch organisation for maintenance of the national railway network infrastructure, the perspective of the Nationale

Spoorwegen (NS), the Dutch principal passenger railway operator, and from the perspective of the three main emergency services the police, fire fighters and medical services. These descriptions were also summarised in a table with a chronology of the most important events. (See Figure 1 for a fragment of this timeline.) Also, summaries of interviews with people from various organisations involved with the emergency response are provided. By this means, the adequacy of the response of each of the involved parties can be analysed and evaluated separately.

In the formalisation process, the three descriptions of the events during the calamity and the condensed timeline were used to extract the locations, actions and communications of the parties involved. Additionally, screenshots of the screens available to the railway traffic controller were used to determine the locations of the trains inside the tunnel tubes and alongside the platforms at the Schiphol train station.

FORMALISATION

In order to be able to check properties of the emergency response to the incident automatically, first a formal trace must be constructed. This process of formalising the textual description of the events into a computer-readable format equates translating the highly qualitative data into a combination of temporal logical and numerical statements (Bosse et al. 2009). In order to do so, the relevant actors, locations and concepts must be identified, and correspondingly an ontology should be specified. A partial specification of this domain ontology is provided in Table 1.

The main concepts used to formally describe the emergency response to the incident are *world states*, *observations* of information elements by agents, *communications* of information elements by agents to agents, and *actions* by agents. The world states include the locations of actors, the occurrences of signal and railroad switch malfunctions, and the belongs-to relations between actors and organisations. The observations state the information elements that agents perceived, and the communications state how one agent shared a certain information element with another agent. These communicated information elements concern, for example, locations of signs of fire, intentions for actions, requests for information, permission for actions, approvals of permissions, or isolated fragments of information, such as the fact that passengers are panicking or that the fire source is not found yet. Correspondingly, the actions concern, for example, entering and exploring the tunnel tubes by the fire fighter teams, evacuating the platforms, converting the trains in the tunnel tubes and vacating the tunnel.

Table 1: Partial Specification of the Domain Ontology

Predicate Inf	ormal meaning
world_state(I:INFO)	The information element I holds in the world.
observation(A:AGENT, I:INFO)	Agent A observes information element I.
communication_from_to(A:AGENT, B:AGENT, I:INFO)	Agent A communicates information element I to agent B.
performed(A:AGENT, ACT:ACTION)	Agent A performs action ACT.

Sort El	ements
AGENT	{RTC1, RTC2, CT756, CT3558, AFO, Schiphol_employee, CCS,…}
ORGANISATION	{ProRail, NS, Schiphol, Police, FireFighters, Medics, RMP, …}
LOCATION	{tunnel1A, tunnel2A, platform12, platform34, Schiphol_station, …}
ACTION	{dispatch_to(L:LOCATION), evacuate(L:LOCATION), convert_train…}
INFORMATION ELEMENT	{at_location(weak_signs_of_fire,platform34), request(info(situation), request(permission(enter(tunnel))), request(action(stop_train)), permission(vacate_tunnel), sign_clear(firefighters), panic_in_train, fire_source_not_found, …}

Using the ontology depicted in Table 1, the response to the Schiphol train tunnel incident was formalised in the software tool based on the language Leadsto (Bosse et al. 2005). This language is an extension of order-sorted predicate logic that allows for representation of both quantitative and logical data. Figure 2 is a screenshot of a fragment of the resulting trace, and Figure 3 shows the corresponding visualisation, where the presence of a black bar indicates that the statement is true at the corresponding time point. Each time interval in the trace represents half a minute.

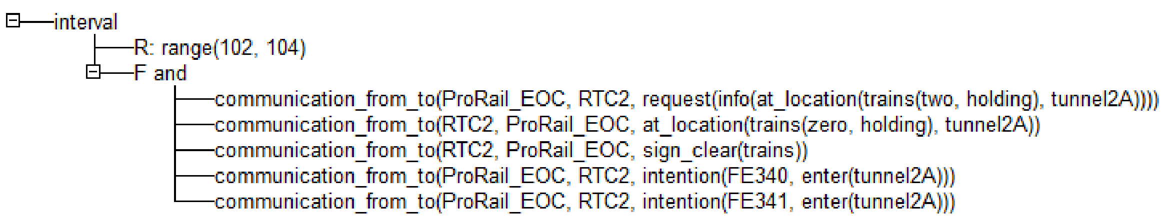

Figure 2: Fragment of Formal Trace

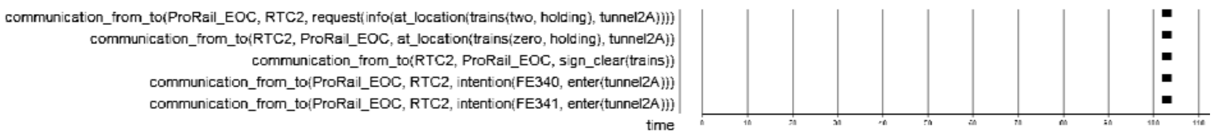

Figure 3: Fragment of Visualisation of Formal Trace.

Automatic Property Checking

This section addresses the analysis of the empirical trace of the fire incident in the Schiphol tunnel, by specification and verification of a number of dynamic properties that have been identified and formalized in the Temporal Trace Language (TTL) and were automatically checked (Bosse et al. 2009). Via a software tool based on TTL, it has been checked whether certain expected (dynamic) properties, expressed as statements in the TTL, hold for a given trace (defined as a time-indexed sequence of states). The purpose of checking the trace for these dynamic properties is to automatically check if important characteristics of net centric incident management hold in the empirical trace and if mistakes were made in communications and actions. This analysis is an innovative way to check for mistakes or find important characteristics of behaviour in the empirical data that is available during or after crisis management.

The TTL software environment includes a dedicated editor supporting specification of dynamic properties to obtain a formally represented temporal predicate logical language TTL formula. In addition, an automated checker is included that takes such a formula and a set of traces as input, and verifies automatically whether the formula holds for the traces. The language TTL is built on atoms referring to states of the world, time points and traces. In addition, dynamic properties are temporal predicate logic statements, that can be formulated with respect to traces based on a state ontology.

Below, a subset of the dynamic properties that were identified for the empirical trace of the fire incident in the Schiphol tunnel are introduced, both in semi-formal and informal notation (where state(γ, t) |= p denotes that state p holds in trace γ at time t). Only a subset of properties is shown, in order to keep the paper concise. Following every property, an evaluation on the empirical trace is discussed. See (Bosse et al. 2009) for more technical details. Properties P1A and B are analysing if the fire was under control on time and the evacuation was performed on time at the correct location. P2A to D are analysing the communications between organisations. P3A and B are analysing the time between requests for permission and the given permissions.

P1A – Fire_Under_Control _Within_15_Minutes

For all time points *t1* and *t2*, all AGENTS *a* and *b* in trace *γ*, if at *t1* there is a fire at location tunnel 2A and there is no earlier time point at which there is a fire at location tunnel2A, and at a later time point *t2*, AGENT *a* communicates to AGENT *b* that the fire is under control, then interval *i* = *t2*-*t1* and *i* ≤ 30.

P1A_FIRE_UNDER_CONTROL_WITHIN_15MINUTES ≡
∀*γ*:TRACE, ∀*t1*,*t2*:TIME, ∀*a*,*b*: AGENTS
state(*γ*, *t1*) |= world_state(at_location(fire, tunnel2A) &
∀*t0*:TIME < *t1* [state(*γ*,*t0*) |≠ world_state(at_location(fire, tunnel2A)] &
state(γ, *t2*) |= communication_from_to(*a*,*b*, fire_under_control) &
t1 ≤ *t2*
⇒
∃*i*:INTEGER
i = *t2*-*t1* &
i ≤ 30

Property P1A can be used to check whether the fire was under control within 15 minutes. This is important to check, because as long as it is not clear if it is a big fire or a small (self stopping) fire, the evacuation should be the first priority, in order to safe as many lives as possible. The result of checking this property in the TTL tool is that this property does not hold in the trace; a time gap of 125 intervals = 62.5 minutes was found between the start of the fire and the communication that the fire was under control.

P1B – Evacuation_Performed_Within_15_Minutes_At_Fire_Location

For all time points *t1* and *t2*, all AGENTS *a* and *b* in trace *γ*, if at *t1* there is a fire at location tunnel 2A and there is no earlier time point at which there is a fire at location tunnel 2A, and at a later time point *t2*, AGENT *a* communicates to AGENT *b* that the tunnel is clear of trains, then interval *i* = *t2*-*t1* and *i* ≤ 30.

P1B_EVACUATION_PERFORMED_WITHIN_15MINUTES_AT_FIRE_LOCATION ≡
∀*γ*:TRACE , ∀*t1*,*t2*:TIME, ∀*a*,*b*: AGENT
state(*γ*, *t1*) |= world_state(at_location(fire, tunnel2A) &
∀*t0*:TIME < *t1* [state(*γ*, *t0*) |≠ world_state(at_location(fire, tunnel2A)] &
state(*γ*, *t2*) |= communication_from_to(*a*,*b*, sign_clear(trains)) &
t1≤*t2*
⇒
∃*i*: INTEGER
i = *t2*-*t1* &
i ≤ 30

This property can be used to check whether the evacuation of the tunnel (fire location) was performed within 15 minutes. This property was not satisfied in the trace, because the time between the start of the fire and the evacuation of the tunnel was 55.5 minutes, since interval *i* = 111 time steps.

P2A – Communications_Between_Organisations

At time point *t* in trace *γ*, AGENT *a* communicates to another AGENT *b* INFO_ELEMENT *k*, and agent *a* belongs to an ORGANISATION *o1* and agent *b* belongs to an ORGANISATION *o2*, and *o1≠o2*.

P2A_COMMUNICATIONS_BETWEEN_ORGANISATIONS(*γ*:TRACE, *t*:TIME, *a*,*b*:AGENT, *k*:INFO_ELEMENT) ≡
∃*o1*, *o2*:ORGANISATION
state(*γ*, *t*) |= communication_from_to(*a*, *b*, *k*) &
state(*γ*, *t*) |= world_state(belongs_to(*a*, *o1*)) &
state(*γ*, *t*) |= world_state(belongs_to(*b*, *o2*)) &
o1 ≠ *o2*

P2B – Sum_Communications_Between_Organisations

For all traces *γ*, time points *t*, AGENT *a* and *b* and INFO_ELEMENT *k*, every time P2A holds, add 1 to the sum that starts with 0.

∀*γ*:TRACE, ∀*t*:TIME, ∀*a,b*:AGENT, *k*:INFO_ELEMENT
∃*n*: Σcase(
P2A_COMMUNICATIONS_BETWEEN_ORGANISATION(
γ, *t*, *a*, *b*, *k*), 1, 0) = *n*

P2C – Communications_Within_Organisations

At time point *t* in trace *γ*, AGENT *a* communicates INFO_ELEMENT *k* to another AGENT *b*, and agent *a* belongs to an ORGANISATION *o1* and agent *b* belongs to an ORGANISATION *o2*, and *o1=o2*.

P2C_COMMUNICATIONS_WITHIN_ORGANISATIONS(*γ*:TRACE, *t*:TIME, *a*,*b*:AGENT, *k*:INFO_ELEMENT) ≡
∃*o1*, *o2*:ORGANISATION
state(*γ*, *t*) |= communication_from_to(*a*, *b*, *k*) &
state(*γ*, *t*) |= world_state(belongs_to(*a*, *o1*)) &
state(*γ*, *t*) |= world_state(belongs_to(*b*, *o2*)) &
o1 = *o2*

P2D – Sum_Communications_Within_Organisations

For all traces *γ*, time points *t*, AGENT *a* and *b* and INFO_ELEMENT *k*, every time P2C holds, add 1 to the sum that starts with 0.

∀*γ*:TRACE, ∀*t*:TIME, ∀*a,b*:AGENT, *k*:INFO_ELEMENT
∃*n*: Σcase(
P2C_COMMUNICATIONS_WITHIN_ORGANISATION(
γ, *t*, *a*, *b*, *k*), 1, 0) = *n*

Properties P2A and P2C check whether there exists a certain communication k between agent a and b. Properties P2B and P2D, respectively count the number of times P2A or P2C hold in the trace. This way, the number of times that there are communications between agents of different organizations and of the same organization, are counted. This is useful information, because the ratio can give an insight in the quality of information sharing between organisations – one of the characteristics of a net centric approach to incident management. The result for the Schiphol trace is that there are 120 communications between organizations and 103 communications within organizations.

P3A – Time_Between_RequestPermission_And_Permission_To_Enter_Tunnel1A

For all time points *t1* and *t2* and all AGENTS *a* and *b* in trace *γ*, if at *t1* agent *a* requests to enter tunnel1A_north to agent *b* and at a later time point *t2*, agent *b* communicates a permission to enter tunnel 1A_north to agent *a*, then interval *i = t2 - t1*.

P3A_TIME_BETWEEN_REQUESTPERMISSION_AND_PERMISSION_TO_ENTER_TUNNEL1A ≡
∀*γ*:TRACE , ∀*t1*,*t2*:INTEGER, ∀*a*,*b*: AGENT
state(*γ*, *t1*) |= communication_from_to(*a*, *b*, request(permission(enter(tunnel1A_north)))) &
state(*γ*, *t2*) |= communication_from_to(*b*, *a*, permission(enter(tunnel1A_north))) &
t1 < *t2*
⇒
∃*i*:interval
i = *t2* - *t1*

P3B – Time_Between_RequestPermission_And_Permission_To_Vacate_Tunnel

For all time points *t1* and *t2* and all AGENTS *a* and *b* in trace *γ*, if at *t1* agent *a* requests a permission to vacate the tunnel to agent *b* and at a later time point *t2*, agent *b* communicates a permission to vacate the tunnel to agent *a*, then interval *i = t2 - t1*.

P3B_TIME_BETWEEN_REQUESTPERMISSION_AND_PERMISSION_TO_VACATE_TUNNEL ≡
∀*γ*:TRACE , ∃*t1*,*t2*:INTEGER, ∀*a*,*b*: AGENT
state(γ, *t1*) |= communication_from_to(*a*, *b*, request(permission(vacate_tunnel))) &
state(γ, *t2*) |= communication_from_to(*b*, *a*, permission(vacate_tunnel)) &
t1 < *t2*
⇒
∃*i*:interval
i = *t2* - *t1*

The properties P3A en P3B check how much time elapses between a request for permission and the permission. Property P3A holds for 1 time step = 30 seconds and P3B holds for 14 time steps = 7 minutes.

In sum, automatic property checking indicated that the fire was not under control within 15 minutes and that the evacuation was not performed on the correct fire location within 15 minutes. These results show that the fire incident was a near miss situation: if the fire would not have gone out by itself, people stuck in the trains in tunnel 2A could have died. Furthermore, there were more communications between organizations than within organizations in our trace. However, the communications within organizations were partially neglected, because these organizations were black-boxed in the report. Therefore, one should be cautious to draw conclusions upon these numbers. With regard to the permissions, one can see that the permission to evacuate the tunnel was relatively time expensive, due to the fact that this was a next step in the whole procedure, whereas the decision to enter the tunnel already was part of the action and followed immediately after the request.

DISCUSSION

The goal of this paper was to show how automatic property checking can be a more efficient and practical method to study crisis coordination processes. Communications and actions during the fire incident that occurred on July 2[nd] 2009 in the train tunnel and underground train station of Amsterdam Airport

Schiphol were analysed. Although this fire turned out to be harmless, the organisations involved in the emergency response proved to be ill-prepared for a serious fire that could occur in any tunnel. A serious, explosively growing tunnel fire can be lethal within 15 minutes. Automatic property checking showed that fire was not under control on time and that the evacuation was not performed within 15 minutes on the exact fire location and the permission to evacuate the tunnel was relatively time expensive.

Overall, according to a net centric approach, the information network must support quick and effective decision making, where for example urgent requests prompt quick and adequate reactions. Understanding critical communication processes can then assist in simulating and providing advice about more effective communication strategies that meet currently unfulfilled needs in both practice and research. Research is predominantly focussed on organisational structures, but decision making in crises occurs ad-hoc and under conditions of significant chaos. In such situations, adaptive communication strategies are needed. Current procedures specify rigid communication links within organisational disciplines, where only higher ranking officials coordinate between the parties involved. In practice, this leads to a fragmented spreading of information in the network of people involved in the crisis response. Information travels along lengthy, inefficient communication chains. New information, including requests and permissions to take urgent actions, takes long to travel and often goes lost. The properties in our analysis were designed to indicate where in the formal trace of the events these processes succeed or require the development of alternative communication strategies drawing on NCC. The results show where in the trace of events the communication went wrong and indicate that there is room for improvement, namely following a more net centric communication strategy.

Although the current research shows that automatic property checking can be a more efficient and practical method to study crisis coordination processes, the current formalisation process still requires a lot of hours work. Part of future work is to make this process automated to save time. Other future work concerns planned comparisons of the formalised data of the Schiphol fire incident with agent-based simulations according to a more net centric approach. The (dynamic) properties from Section 4, amongst others, can then be used again. Since the TTL tool can take both simulated and empirical traces as input, it can be used to check (automatically) whether the generated simulation runs show similar patterns to the real world transcripts.

Finally, since there are lots of incidents all over the world, more case studies can be used to validate the proposed approach. This research contributes to previous work mentioned in this area (e.g. Hoogendoorn et.al 2008; Boss et al. 2008; Bosse et al. 2009; Bosse et al. 2011, Bosse and Mogles 2012).

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