Designing an Agent-Based Model of SMEs to Assess Flood Response Strategies and Resilience

C. Li, G. Coates, N. Johnson, M. McGuinness

***Abstract*—**In the UK, flooding is responsible for significant losses to the economy due to the impact on businesses, the vast majority of which are Small and Medium Enterprises (SMEs). Businesses of this nature tend to lack formal plans to aid their response to and recovery from disruptive events such as flooding. This paper reports on work on how an agent-based model (ABM) is being developed based on interview data gathered from SMEs at-risk of flooding and/or have direct experience of flooding. The ABM will enable simulations to be performed allowing investigations of different response strategies which SMEs may employ to lessen the impact of flooding, thus strengthening their resilience.

***Keywords*—**ABM, Flood response, SMEs, Business continuity.

I. Introduction

SMALL and Medium Enterprises (SMEs) are the backbone of the UK economy accounting for 99.9% of businesses, 59.1% of private sector employment and 48.8% of private sector turnover [1]. Any disruption to the operations of these businesses will propagate beyond the directly-affected geographical area having a considerable impact on the entire economy. Increasingly, flooding is seen to be a significant risk which has the potential to disrupt SMEs' operations. Environment Agency estimates put the financial cost to UK business in 2007 at £740 million [2]. Figures such as this have raised flood risk management on the political agenda. Further, means of reducing the susceptibility of business operations to flooding is receiving growing attention. SESAME is a research project which is investigating SME flood response and recovery in the UK with the aim of informing future enhanced organizational resilience [3].

The purpose of the paper is to present two strands of the SESAME project. Firstly, aspects of SMEs' experience of flooding are discussed drawing upon semi-structured interviews conducted with businesses in two geographical case studies. Secondly, based on this interview data, aspects of the design of an agent-based model (ABM) are presented, which will be used to represent SMEs faced with flooding in dynamic simulations of a flood event.

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II. Related Work

A. Business Response and Recovery to Flooding

There is a limited but growing body of research concerned with the impacts of flooding on SMEs in the UK. What much of the research appears to have in common is that it is focused on various forms of impact upon SMEs including direct and indirect impacts [4], duration of impacts [5], [6], and tangible and intangible impacts [7], from an external perspective. Although research has identified various characteristics of SMEs, notably their resource constraints [8], [9] and lack of organizational slack [10], knowledge of how these characteristics of SMEs influence their response, recovery, and adaptation capabilities remains underdeveloped.

According to [11] "SMEs often tend to underestimate the risk of flooding which tends to have a low priority in their business agenda." They found that SMEs have implemented different property-level protection measures (structural) and generic business continuity/risk management measures (non-structural) based on their requirements to achieve a desired level of protection. These measures may be influenced by the type of business and any history of previous floods.

B. Business Continuity Management

Organizations face increasing threats and uncertainty from climate change and associated extreme weather events. Since the new millennium, business continuity management (BCM) has emerged as a process to help organizations manage such threats and facilitate long term sustainability. BCM has been defined as an "holistic management process that identifies potential threats to an organization and the impacts to business operations those threats, if realized, might cause, and which provides a framework for building organizational resilience with the capability for an effective response that safeguards the interests of its key stakeholders, reputation, brand and value-creating activities" [12]. BCM's 'plan, do, check, act' logic provides a useful template for organizations to build flood risk management capability and strengthen their resilience. An independent review following the UK floods in 2007 highlighted the role of BCM as part of any successful organizational flood response [13]. However, in the UK organizational engagement with BCM remains scarce with less take-up by SMEs and third sector organizations, relative to larger organizations and public sector bodies [14].

C. Modelling Businesses in the Context of Disruptive Events

Agent-based simulation models have been highlighted as a means of gaining an understanding of complex adaptive systems such as business relations and networks [15] and

reproducing the interactions between different organizations in an artificial environment [16]. It has been asserted that, unlike traditional static data capture and analysis methods, agent-based simulation models enable systematic investigations into the dynamic and evolutionary nature of business relations and networks [17]. Indeed, in the context of SMEs, research into agent-based models, or complex adaptive systems, has included modelling the evolution of SMEs [18] and the dynamic growth process of SMEs [19], investigating SME supply chains [20] and predicting the impact of public policies on SMEs [21]. However, while modelling small businesses as complex adaptive systems has been advocated for some time [22], research to date has focussed on conceptualizing agent-based models of SMEs rather than on their implementation. Consequently, it is understandable that research into agent-based models of SMEs in the context of responding to disruptive events, in particular flooding, has yet to be undertaken. This lack of research, coupled with the limited work undertaken to date in understanding how SMEs currently respond to extreme weather events, such as flooding [23], [24], presents a significant challenge to researchers.

III. SMEs' Experience of Flooding

A. Research Methods

This paper draws on data from the SESAME project. Findings are drawn from two geographically based case studies in the UK, both of which suffered major flooding in 2007. The purpose in presenting these findings is to illustrate the process by which these data are utilized to inform the development of an ABM in which SMEs are the agents modelled, rather than modelling individuals which has been the predominant focus in previous research.

A qualitative approach has been taken to data collection, conducting a series of semi-structured interviews with SMEs in each case study area. Data gathered from relevant stakeholder organizations, which provides support and/or training to SMEs, is also included. Through this triangulation of data, critical insights are sought into SMEs' behaviours with respect to flood response and recovery. The data referred to in this paper is drawn from a total of 39 in-depth interviews (case study 1 (C1): 22 interviews; case study 2 (C2): 17 interviews), which range in duration from 45 minutes to two and a half hours.

B. Analysis of Interviews

The interviews were audio recorded, with the participants' consent, before being transcribed. These transcriptions are then entered into Nvivo software in which a coding process is undertaken whereby patterns, themes and relationships between themes are identified [25]. These patterns and themes then form the basis for attributes and behaviours which inform the development of models for the ABM.

C. Findings

In this section, two themes are highlighted, which have emerged from an analysis of the two case studies; resource utilization and insurance.

A firm is a bundle of resources [26]-[29] comprising of tangible assets e.g. plant, machinery, facilities and human capital as well as intangible assets e.g. networks, brand and reputation. Over time, particular knowledge sets and capabilities develop around these resources which are then reflected in firm level processes and activities. These unique resources and/or distinct capabilities, which differ from those of competitors, and which competitors cannot easily secure or copy, provides the firm's basis for competitive advantage and its ability to sustain superior performance. Preparedness for disruptive events, through for example established BCM, can represent a significant organizational capability.

Findings from case studies 1 and 2 strongly indicate that the vast majority of SMEs did not have formal BCM provision or plans. When asked why this was the case, typical responses from interviewees referred to a lack of knowledge and expertise in BCM as well as the time and resources to develop such plans. In the context of the 2007 floods, many interviewees expressed the view that their business had no plans in place, with the flood taking them wholly by surprise and often relying upon ad hoc response based upon plans which existed "in the head".

Despite a lack of BCM, the businesses interviewed had demonstrated the ability to respond and recover from a major flooding event. How was this possible? What can be gleaned from the data is that SME resilience emerged from the ability to configure firm resources in novel ways to address the exigencies of the flood event. Utilizing existing resources, accessing resources outside of the firm and leveraging social capital formed the platform for effective response and recovery in the most resilient of SMEs.

1) Resource Utilization: Bricolage and Improvisation

Resourcefulness and creative resource utilization are the cornerstones of bricolage, which has been defined as "making do with current resources and creating new forms and order from tools and materials at hand" [30]. Illustrating this is the example of an engineering business which manufactures wire products for a range of commercial and household uses. When the factory and adjacent premises became inundated with flood water, staff utilized their wire and fixing devices to create a safety rope across a flooded road thereby enabling stranded workers to evacuate the premises and make their way to safety. In a similar vein, another interviewee observed, "We kind of used our own resources. This is the sort of thing we do, building, refurbishment works and things like that… So we have got the contacts there, it was getting the right kind of people in at the right time."

Accessing and acquiring resources beyond the boundary of the firm itself, emerges as a theme from the data also. The leveraging of social capital, through using personal contacts as a means of identifying and securing resources to mitigate flood impacts, is evident. This can also be characterized as network bricolage, that is, "dependence on pre-existing contact networks as the means at hand" [31]. Engaging in this process allowed SMEs to: identify and secure alternative premises; acquire generators and dehumidifiers; access skilled

tradespersons via contractor networks, resulting in rapid refurbishment of offices. At a time, immediately post flood event, when these types of resources may be in high demand and short supply, network bricolage is a powerful tool in helping SMES to minimize the length of business disruption for the firm.

It is plausible to suggest that this resourcefulness; bricolage and improvisation, and concomitant resilience, is influenced by those broad SME characteristics described previously. Whilst 'firefighting' [32], [33] may not always be the most efficient means of dealing with everyday problems, one consequence of this approach is that, in the event of a major disruption, managers and employees can be adept at responding innovatively, flexibly and quickly to solve the organizations problems arising – key attributes underpinning organizational resilience.

2) Insurance

For many organizations the provision of adequate insurance cover as part of their flood risk management arrangements, and being able to successfully claim for losses within a relatively short time following the impacts of flooding, will contribute to minimizing the period of business interruption and help to facilitate a rapid and full recovery process. For organizations without adequate insurance the impact of flooding may present challenging consequences or even result in a business failing altogether.

In the two case studies, SMEs have been found to hold mixed opinions of their insurers and the claims process following the impacts of flooding. Findings suggest that strong client/broker relationships, which embody a degree of shared loyalty, can support a successful claim. SMEs that approached their insurance claim in a methodical fashion, photographing and cataloguing damage, were able to provide hard evidence of their losses which supported a satisfactory claim.

It was not uncommon for insurers/loss adjusters to attend flood affected businesses within 2-3 days, and although claim process times varied, in part due to the uncertainty surrounding the extent of longer-term impacts on e.g. machinery, most respondents expressed satisfaction that their claim had covered actual losses, for example "we worked through a broker and they were very helpful and then we got these guys coming in, the loss adjusters, who came in and they were really helpful."

There are, of course, exceptions and not all respondents expressed a positive view of their insurers or the claims process after the impacts of flooding. One firm highlighted how delays and ultimately an unsatisfactory insurance settlement affected their business negatively, in the short and medium term, throwing into sharp focus how resource constraints can create additional vulnerability for SMEs. For instance one interviewee stated "So we had been hung out to dry for at least 4 or 5 months (by the insurers), borrowing stuff, putting stuff out, not able to manufacturer on site because we haven't got the capital to buy new equipment…".

The data collected in the case studies suggest claiming for business interruption and lost revenue is no less problematic. When submitting a business interruption claim to insurers it can be difficult to quantify the interruption. One SME provided graphs of previous years' business and used these to show comparisons to the post-flood recovery period, thereby justifying their business interruption claim.

Due to the difficulties of quantifying the impacts of flooding, one SME negotiated a staged approach with their insurers to get machinery and equipment working again. First, they prioritized a temporary fix schedule of some equipment to ensure a degree of continuity of operations. Second, they agreed a longer-term approach to servicing and rewiring other machinery.

The speed at which an insurance claim is processed may impact some SMEs more than others. For example, it may be dependent upon the extent to which the SME is 'cash rich'. Some SMEs suggested they had sufficient cash reserves to 'weather the storm', but without those reserves they could have gone out of business.

Another context where the speed of a claim process may be critical to an SME's survival is the extent to which it is lifestyle or growth orientated [34], [35]. It was found that with business interruption and wages/earnings cover, a ''lifestyle' SME may be content to wait long periods for a claim to be processed. However, if an SME is on a growth trajectory there may be more of an incentive to settle their claim as quickly as possible. One SME interviewed was enjoying a period of growth when flooding occurred and the claims process delayed the purchase of a company thereby slowing down this growth.

IV. Design of an Agent-Based Model of SMEs to Assess Their Response to Floods

As alluded to earlier, an aim of this research is to use agent-based modelling and simulation, allied with interview data based on SMEs at risk and/or with experience of flooding, to conduct computational experiments to investigate varying strategies SMEs may employ when responding to flood events. Such simulations will enable relationships to be established between independent input variables and dependent output variables. For example, a range of flood scenarios could be played out involving a variety of SMEs implementing different levels of business continuity plans. Thus, a greater understanding could be gained of the relationship between SMEs' resilience to flooding and different actions such as erecting flood defences, moving stock, adapting premises, varying levels of insurance cover for property damage and business interruption, registering for Environment Agency flood alerts, and engaging in mutual aid.

Agent-based modelling and simulation is being used in this research as it offers an approach which allows each SME within a network of businesses to be represented as an individual entity such that assessments can be made of how their behaviour, interactions and relationships influence business operations when faced with a flood event. Furthermore, this ability to assess the effect of decisions made when faced with flooding and evaluate the corresponding operational implications provides a mechanism to identify

those behaviours which may present the greatest opportunity for SMEs to improve the way in which they prepare for, respond to and recover from flood events.

A. Manufacturing and Engineering SMEs

Initially, agent-based model design has focused on manufacturing SMEs. The rationale for focusing on this type of SME is that such firms have been reported as suffering significant economic loss and severe disruption to productivity due to damages to their premises, equipment, machinery and stock. For example, it has been reported that as a result of the 2007 floods in Sheffield in the UK, the cost of flooding to some businesses ran into tens of millions of pounds, with one company suffering £15 million worth of damage [36]. Due to the focus on manufacturing SMEs, the majority of the interviews referred to in Section III were conducted with this type of business.

B. Agent-Based Model

In this section, an overview is provided in terms what agents are to be modelled, the attributes and behaviour rules of SME agents, the environment in which SME agents operate and how these agents sense their environment and communicate with other agents.

1) Agents

As referred to earlier, manufacturing SMEs provide the current focus in terms of agents to be modelled. Gaining an understanding and insight into the effect of the actions taken by these firms on business operations and performance when responding to and recovering from a flood event is of key importance in this research. In modelling manufacturing businesses, dimensions such as size in terms of number of employees is incorporated. That is, account is taken of SME category where up to 9 employees signifies a micro firm, between 10-49 a small firm and between 50-249 a medium sized firm. Further, manufacturing SMEs are modeled according to the type of product(s) manufactured and the quantity produced within a given time period. Also, it is anticipated that in addition to SMEs of the nature described, small firms from other sectors will be modelled to investigate the effectiveness of actions taken in responding to and recovering from flooding according to sector of SME.

Other agents to be modelled due to their relationships with SMEs include customers and suppliers, service companies such as plumbers and electricians, and the emergency services. However, given the focus of this research on SMEs, these agents will be modelled in less detail. Also, organizations modelled as 'environment' agents include the Environment Agency (EA) and Meteorological Office, which provide flood alerts and warnings that could potentially cause businesses to take action prior to flooding. For example, simply moving equipment and stock, where possible, prior to flood water reaching a business' premises can avoid significant losses.

2) Agent Attributes and Behaviour Rules

In this research, three sources are considered when defining the attributes and behaviour rules of SME agents: transcripts of interviews conducted with businesses as discussed in Section III; ISO 22301 on Business Continuity Management Systems requirements [12]; the EA's guidelines for businesses to prepare for floods [37]. This paper focuses on the transcripts of interviews conducted with businesses.

In this paper, a flood event has been divided into two main phases, namely (i) the pre-flood and during flood phase which covers the period from SMEs receiving flood alerts/warning through to the point when the flood water has receded, and (ii) the aftermath phase which covers the period in which SMEs clean up the premises and recover from the disruption. However, it is acknowledged that this division between the periods defined as during the flood and the aftermath of the flood are not clearly differentiable and can overlap. For illustrative purposes, Figs. 1 and 2 provide high level overviews of some aspects of the processes followed by SMEs in responding to the two phases of a flood event.

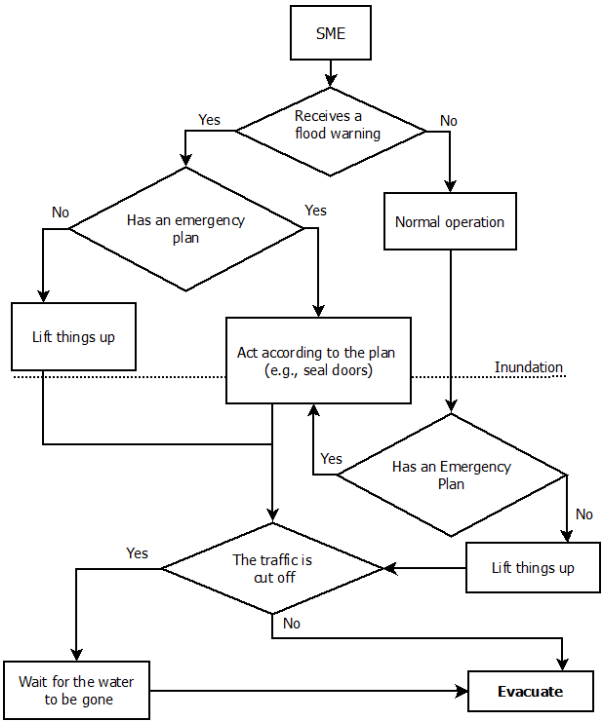

Fig. 1 Phase 1: Pre-flood and during flood

As illustrated in Figs. 1 and 2, an SME agent will behave, i.e. make decisions and follow certain courses of action, according to the phase of the flood and the prevailing conditions including those related to the environment.

In phase 1, decisions and actions taken by an SME agent will depend on, for example, whether or not they subscribe to and/or receive floods alerts/warnings, whether or not they have an emergency plan or business continuity plan in place, and/or whether the premises and/or adjacent roads are breached by flood water. For instance, if an SME agent has subscribed to be issued with flood alerts from the EA environment agent, then these will be received at different points in time depending on the risk of flooding and/or, if a flood is in progress. In contrast, all SME agents are able to

directly access Meteorological Office agent warnings or observe regular updates via the media.

In phase 2, as shown in Fig. 2, decisions and actions taken will depend on, for example, whether and to what degree the business is insured, i.e. are they insured for damage only or damage and business interruption, whether the firm is 'cash rich', whether it has it has pre-existing relationships with service companies, and/or whether it has machinery or stock damaged by floods. Based on these decisions and actions, SME agents have been designed to have a range of behaviours such as raise items from the floor to above flood level; act according to the emergency plan; evacuate; claim insurance; contact service companies; enact clean up which could be undertaken by contractors or by employees.

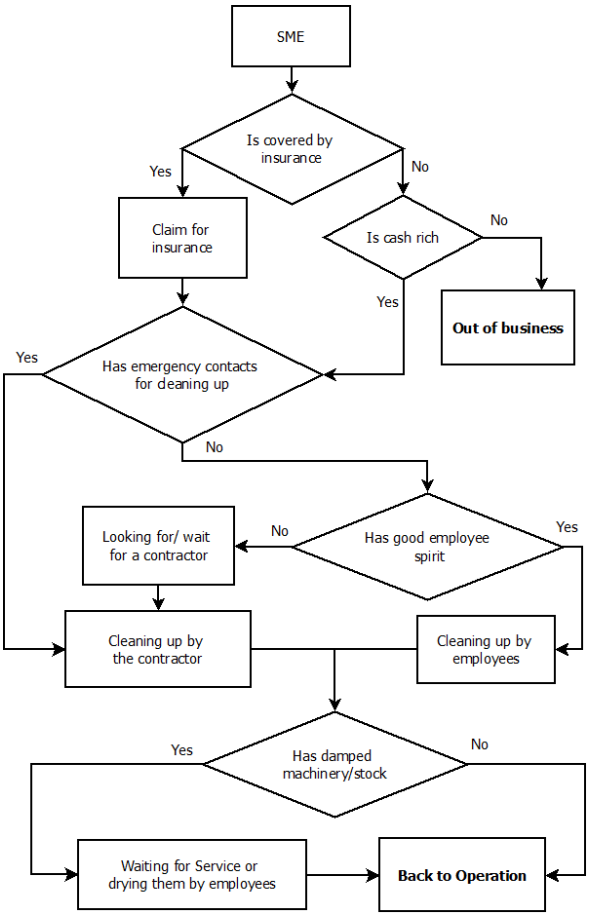

Fig. 2 Phase 2: Aftermath of flood

In consideration of the two phases of a flood briefly discussed, Fig. 3 presents a Unified Modeling Language (UML) diagram related to the design of SME agents and environment agents. This figure indicates agent attributes and behaviors. For example, an SME agent has attributes such as company name, business code, number of employees, turnover and so on. Further, a manufacturing SME agent inherits the attributes of an SME agent, and in addition has attributes related to stock, products and production levels. In turn, stock and products include their own attributes. While not exhaustive, Fig. 3 provides an overview of the nature of attributes and behaviours an SME agent, and a manufacturing SME agent, possess. Each of these attributes and behaviours will be required in the simulation stage of this research, which will involve (i) the use of flood modelling to provide a dynamic inundation prediction in a virtual geographic environment so as to identify the SMEs affected, and (ii) the actions of these businesses being simulated over a 10-14 day period thus enabling an assessment to be made of their performance; as an example a manufacturing firm will be measured in terms of production level.

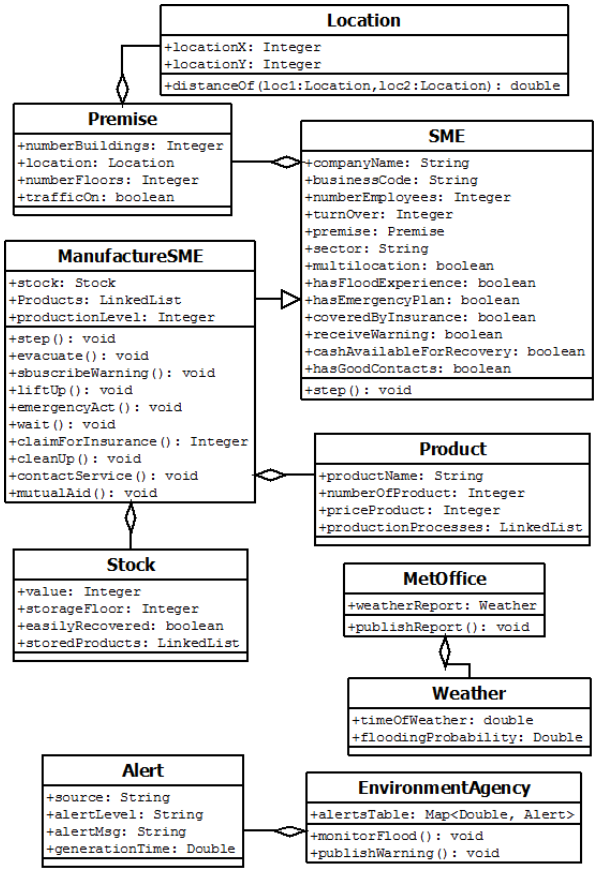

Fig. 3 UML diagram of the agents' design

Also as shown in Fig. 3, an Environment Agency agent has an alert table attribute which contains alerts published at different times. For each alert, information includes source, level, message, and generation time. Also, a Meteorological Office agent has a weather attribute that contains information related the time and probability of flooding. Again, these agent attributes will be an important aspect of agent-based simulation.

C. Implementation of Agent Communication

In addition to the actions SME agents may take as a consequence of sensing their environment, the interactions between agents, via direct communication, will also aid understanding of better preparedness and building community resilience in flooding. The implementation of communication

between agents is being developed using the Repast toolkit[1]. Instances of the agents referred to in Fig. 3 are connected via different projections, which are relationships defined between the agents. These relationships include those between SME agents, between SME agents and service companies, and subscribe-alert relationship between the EA agent and SME agents.

V. Conclusions

Mitigating the impact of flooding on SMEs and facilitating a more rapid recovery post flood offers significant benefits in reducing the direct and indirect economic impact at a local, regional and national level. Given the predominance of SMEs in the business community, furthering understanding of what specific actions could be taken when faced with flooding and, importantly, how these actions are related to business performance is of great significance and a key aim of flood risk management research such as that overviewed in this paper. Gaining such understanding from research findings could inform and influence the behaviours and adaptations of SMEs thus strengthening not only their resilience but that of communities and the entire nation.

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