Proceedings of the Operational Research Society Simulation Workshop 2016 (SW16), 8th
Ettington, United Kingdom, 11-13 April 2016

USING SIMULATION GAMING TO VALIDATE A MATHEMATICAL MODELING PLATFORM FOR RESOURCE ALLOCATION IN DISASTERS

Dr Sara Hasani

University of Bedfordshire
University Square, Luton, Bedfordshire
LU1 3JU
sara.hasani@beds.ac.uk

Dr Emel Aktas

Cranfield University
College Rd, Cranfield
MK43 0AL
emel.aktas@cranfield.ac.uk

ABSTRACT

The extraordinary conditions of a disaster require the mobilisation of all available resources, inducing the rush of humanitarian partners into the affected area This phenomenon called the proliferation of actors, causes serious problems during the disaster response phase including the oversupply, duplicated efforts, lack of planning In an attempt to reduce the partner proliferation problem a framework called PREDIS (PREdictive model for DISaster response partner selection) is put forward to configure the humanitarian network within early hours after disaster strike when the information is scarce To verify this model a simulation game is designed using two sets of real decision makers (experts and non-experts) in the disaster Haiyan scenario The result shows that using the PREDIS framework 100% of the experts could make the same decisions less than six hours comparing to 72 hours Also between 71% and 86% of the times experts and non-experts decide similarly using the PREDIS framework

Keywords: Decision-making, Disaster response, MCDM, Simulation game, Proliferation of partners

1 INTRODUCTION

The Multi-Cluster/Sector Initial Rapid Assessment (MIRA) report is released 72 hours to three weeks after a disaster strikes, and contains valuable information about various impacts of the disaster. The problem is that in the early hours after a disaster strike this report is yet to be released whilst most of the decisions about partners and emergency aids need to be taken. The PREDIS model is an attempt to bridge the gap in the early hours of the disaster aftermath where no official report regarding the human impact and the needs assessment required for disaster response decisions exist. Most of these decisions such as allocation of resources and selecting the partners need to be made before the MIRA report is released in order to prevent fatalities and the spread of disease and so on. This is the period where the PREDIS model is the most useful. The purpose of the PREDIS model is to provide a predictive evaluation of the disaster impact during the first 72 hours after any natural onset disasters. This provides the decision makers during this period with information, which can then be used to allocate the limited resources and recruit suitable partners. In another words this is a decision making platform for making more efficient allocation of the resources, sourced from the most suitable partners chosen for that type of disaster and that level of impact. In this paper the PREDIS model is used in a simulation process where the impact of using model in making decisions is compared to the decisions made without the model In this hypothetical simulation game, there is an intention to investigate how well the model can assist the decision maker in making faster decisions. Also it is investigated that how well the model can assist the non-expert decision makers, make decisions similar to the experts. Simulation games are normally used in the situations when the re-creation of real situation is dangerous or immoral, namely military field or medical field. Disaster situation is also part of this real situations where creating a disaster for the purpose of validating the model is unethical if not impossible

Instead the simulation game re-creates the real world in an observable situation where the decision made by each group of experts and non-experts can be analysed and compared in a safe environment. The research contributes to various areas of disaster management, decision-making and simulation game as well as serious games by being part of the new use of simulation game for validation instead of sole purpose of education. The paper begins with outlining the existing experience in simulation games to paint a picture of how other scholars used this tools to simplify their complex real worlds. Then the principles of the PREDIS model are briefly outlined The process of simulation game then is put forward before the result is analysed. The paper concludes with the summary and the limitations of the study

2 THE EXISTING EXPERIENCE IN SIMULATION GAMES

Simulation as a validation tool itself is defined as a representation of a real-world environment, when the real system may not be observed directly because of the inaccessibility, cost and danger (Barton, 1994). Participatory simulation or simulation games bring the simulation into the experiential world of the players (Colella, 2000). In that sense the simulation games are the most dynamic forms of simulated decision-making models (including discrete choice, stated preference, and agent based modelling) because multiple agents are interacting with each other for decision-making and the effects of the choices are reciprocated by decisions of all agents (Anand, 2013). Although the simulation games are performed in various disciplines, scholars (Elgood, 1997; Lewis and Maylor, 2007) identify 572 simulation games in which almost half (222 games) are related to operations management. Simulation games, which have been used for validating decision-making models in various studies as, provided in table 1

Table 1 *Example of simulation designs*

Subject	Objective	Related work
Servitisation enhancement	Understanding the customer needs and define the scope of servitisation	Laine et al (2012)
Decision-making under uncertainty	Strategic policy formulation	Oderanti and Wilde (2010)
Leadership development	Literature review	Lopes et al (2013)
City logistics	Validating the proposed framework	Anand et al (2013)
Medical decision-making	Understanding the decision-making process	Mohan et al (2014)
		Ben-Zvi et al (2010)
Agricultural policy	Analysis of the impact of a policy	Musshoffa and Hirschauerb (2014)
Economic behaviour	Analysing the Bounded Rationality Behaviour	Musshof et al (2011)
Mergers and Acquisition	Understanding in what economy the mergers and acquisitions take place	Thavikulwat et al (2013)
Strategic decision	Decision about evacuation modelling	Thompson and Merchant (1995)
Decision support system	Efficacy of simulation game	Ben Zvi (2010)
Policy negotiation	Reducing GHG emissions	Sterman et al (2014)
Supply chain management	Effect of coordination risk on bullwhip phenomenon	Croson et al (2014)

Table 1 shows the use of simulation games in the variety of studies; for example in medical treatment (Reichlin et al, 2011) to investigate the effect of increase in the knowledge of the patient on the cancer treatment decision. Another example is the use of agent-based model for designing a serious game to develop an entrepreneurial mind in the user (Gentile et al, 2014). Also simulation is used in cross-cultural decision-making (Madni, 2013) to promote the ad-hoc decision-making in supply chain. These decisions are basically made for a special and immediate purpose, without previous planning; which makes the result difficult to generalise.

It has also been used to validate a model about deciding the profit margin and supply partners in city logistics (Anand et al, 2013). Another example is related to the validation of the decision-making in land use (Villamore, 2013) to examine if rewarding the decision-maker for eco-friendly behaviour instead of profit-oriented behaviour affects the decision In the present research a simulation game is used to highlight the strengths and weaknesses of the model and to justify its usage in the real-world situations. To that end the simulation game is embedded in the treatment phase of a quasi-experiment design as is explained in the next section.

3 THE PREDIS MODEL

The PREDIS model formulates an MCDM platform in combination to linear programing to optimise resource allocation. The input data are drawn from a panel analysis of historical records (4,252 natural onset disasters between 1980 to 2013). This data then is examined using a pattern recognition technique to predict the human impact of the disaster (fatality, injured, homeless) with up to 3% prediction error. This enables the decision makers to estimate the required needs for each disaster and prioritise them based on the disaster type and socio-economic situation of the affected country. It also allows to rank and optimise the desired partners based on the decision maker's preferences. The logic behind this attempt is that if a predictive technique could be developed to approximately estimate the human impact, and the needs of the affected population immediately after the disaster strike, then it is possible to combine the decision makers' expertise and experiences with the data about the available resources to enable decisions about which partner should meet which requirements. The focus of this paper is on the verification of above model using a simulation game The PREDIS model in the simulation game is used in the treatment phase of the quasi-experiment design.

4 SIMULATION GAME

To validate the PREDIS model two hypotheses were considered:

Hypothesis 1: 'The PREDIS model assists the decision makers in making the similar/comparable decisions faster'

Hypothesis 2: 'The PREDIS model assists the non-experts in making decisions as well as experts'

If these hypotheses are confirmed, it can be said that the PREDIS model not only helps the experts to decide faster but also helps the non-experts in making decisions as well as the experts. These hypotheses were examined in a quasi-experimental design (Figure 1) where the simulation game is observed as the treatment to a quota sample selected equally from a mixed population of experts and non-experts. The use of the experimental design in simulation games is popular due to its resemblance to the laboratory conditions (Simon, 1961; Norris and Snyder, 1982; Ben-Zvi, 2010; Musshoff, 2011; Croson et al, 2014). Experimental approaches are used in various studies where participants have to make entrepreneurial decisions within the systematically controlled rules of the game (Longworth, 1969, 2008; Tanner, 1975; Keys and Wolfe, 1990; Musshoff and Hirschauer, 2014).

Figure 1 shows that this empirical study (simulation game) contains three phases of the quasi-experiment design It starts with the pre-test where the participants are asked to decide about a disaster scenario (here disaster Haiyan). At this point they are offered the data in the MIRA report and are asked to make decisions about the requirements and the humanitarian partners using their experience and judgement. The second step is the treatment where the participants are exposed to the principles of PREDIS model In this model the human impact of the disasters is predicted using a rule based technique and the required aids are matched with the available humanitarian partners. The last phase or post-test is where both groups are asked to make decisions using the principles of the PREDIS model In this phase no information is provided other than the date, the type and the country of the disaster.

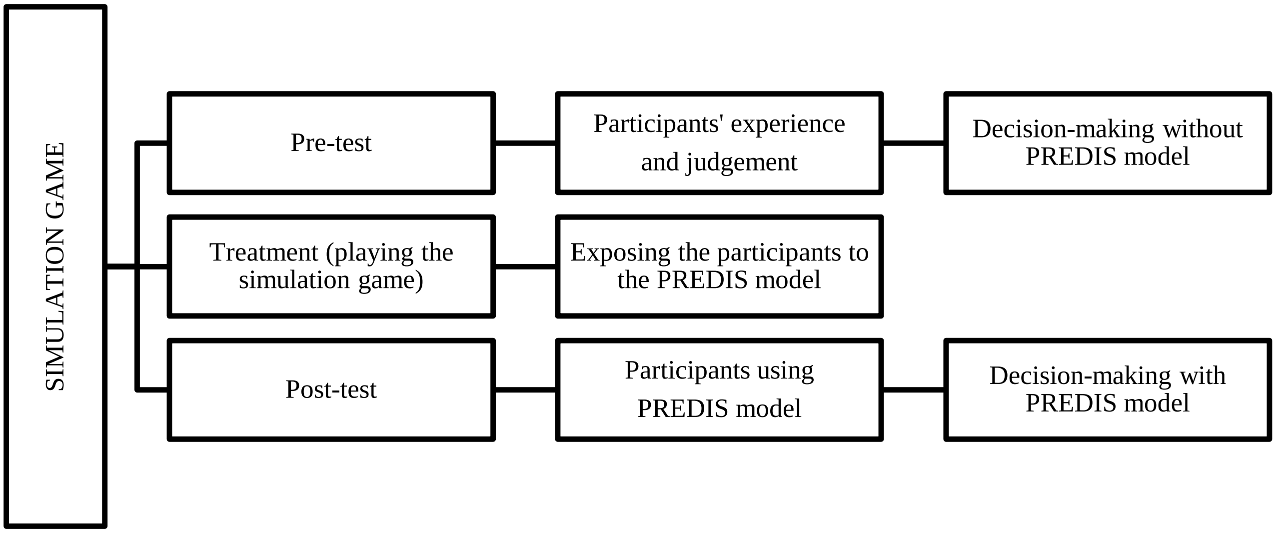

Figure 1 *Mapping the process of quasi-experiment simulation game*

The simulation game process took three weeks to complete for 44 expert and non-expert participants. The expert participants were selected from volunteers who responded to a series of announcements from different humanitarian networks on the related conferences, organisations, Linkedin special interest groups and humanitarian summons. They were gradually filtered after preliminary information regarding the process, their availability and their experience. The numbers in non-expert group then was matched to the remaining experts in order to make the two groups comparable

5 PROTOCOL FOR RUNNING THE SIMULATION GAME

The protocol for the simulation game is built upon Sterman's (1987) example of a simulated game such as a beer game for designing the instructions, strategies and debriefing questionnaires as well as the Van Sickle (1977) version of dangerous parallel for designing the implementation process.

The purpose of the game is twofold: To introduce and evaluate the model and to identify the weakness of the model in a real-world-like situation.

The goal of the first questionnaire is to define the characteristics of the desirable partners in the view of each decision maker and give each criterion the numerical preferences. The data about the characteristics of the desired partner in terms of the following is gathered: Type of the partner (governmental, NGO, International, Military or Volunteer organization), Size of the partners based on ANLAP's (2012) categories for humanitarian organisations), Experience of the partners, Partner's surge capacity (the ability to rapidly expand beyond normal capacity to meet the increased demand), Partner's international expansion and ability to address the needs for humanitarian cluster being WASH, Nutrition, Health, and Shelter. These preferences calculated by AHP are combined with utility function for each resource as well as the utility of that resource for that partner to form an optimisation problem with two restrictions. First restriction shows that the total units acquired from all partners should not exceed the 100% of the total resources required. The second restriction shows that the number of the units obtained from the partner should not exceed the resources available to that partner. The partners then can be ranked based on their utility. For example, for these particular participants, the utility of partners can be calculated and be used to rank the partners as exhibited in table 2.

Table 1 *Example of partners ranked / participant's preferences*

Rank	Partner	Total Utility	Type	Size	Expansion	Experience	Surge capacity
1	5	15205	Government	Small	Yes	Low	Low
2	14	13716	Government	Small	No	Low	Low
3	18	13549	Government	Small	Yes	Low	Very high
4	12	13078	Government	Small	Yes	High	High
5	16	11643	Government	Medium	Yes	Low	Very high

Table 2 shows an example of the rankings of the partners based on this participant's preferences. For example, Partner 5 is the most desirable partner with a utility of 1520. This also shows that the most desirable partners for these participants are small governmental entities. In addition, it seems that this participant does not value the experience or the surge capacity of the partners as critical requirements for a disaster response.

6 THE RESULT

To compare the result between the two groups of experts and non-experts, a variation of outranking method associated to Borda (Marchant, 1996) or Roy (Bouyssou, 2001) has been employed. The reason is that this is a classic MCDM problem, where a set of alternatives is selected based on preferences expressed by decision maker (Buoyssou, 2001). A common solution is to examine if for example, partner (a) is at least as good as partner (b). The outranking techniques under this rule have been used to support decision-making in voting (Jurij, 2006), supplier selection (De Boer et al, 2008) or project assessment (Nurmi and Salonen, 2008) amongst others. If a selection consists of a set D of Decision makers (here 22 decision makers for each group), each having a preference order for a set of C candidates (here 20 partners), the Borda rule here is calculated where a partner receives *n* points each time they are selected as the most desirable, *n-1* points when they are selected second to most desirable, and no points every time they are selected as the least desirable (Russell, 2007). An example of these results for experts is exhibited in Table 3.

Error! Reference source not found. shows that the total Borda count for partner 1,2,3,4 is calculated as 144, 456, 326, and 500. This means that in this set, partner 4 is the most desirable in the overall view of the experts. The final results of the Borda counts are calculated for experts and are ranked in table 4.

Table 4 shows that based on the Borda count, for the group of experts, partner 4 who is a small military organisation with a high surge capacity, no international expansion, and low experience is the most desirable (with a 500 Borda count). Partner 9, who is a medium sized government organisation with no expansion, and a high degree of experience and surge capacity is the least desirable (with a 105 Borda count). The same process has been repeated for the non-expert group and the comparison of the result shows that for example the non-experts preferred partner 5 and 12 equally (333 Borda count) mostly because they are both small governmental organisations, with international expansion. It seems that the non-experts care less about the surge capacity and experience. Their least favourite are partners 20 and 17 with (a 135 and 136 Borda count), who are very big organisations with international expansion, and low surge capacity and experience.

As far as the comparison of first and last choices of the experts and non-experts reveals, there is no evidence that by using the PREDIS model these two groups make the same choices. However, the NRMSE has been used to calculate a more precise percentage of error between the choices of the two groups. The NRMSE for difference between the two is calculated as 29% (Error between non-experts and experts) and 14% (Error between experts and non-experts). This means that at least 14% and at most 29% of the times, the non-experts' choices are different from the experts. This also means although the first and last choice of the majority of decision makers in the two groups are not the same, between 71% and 86% of the times experts and non-experts decide similarly using the PREDIS framework. The significance of this result is that the non-expert does so with no prior training or data other than the data that are freely available on the Internet through the UN related and World Bank related websites (including HDI, DRI, population, population density, and disaster type). Therefore, it is possible to conclude that although the result shows that the experts and non-experts may have various preferences, the model enables the non-experts to choose partners similarly to experts, if necessary.

Table 3 *Example of the Borda count for the group of experts*

		Partner 1		**Partner 2**		**Partner 3**		**Partner 4**	
Choice	**N**	**Frequency**	**Borda**	**Frequency**	**Borda**	**Frequency**	**Borda**	**Frequency**	**Borda**
1st	n	0	0	2	40	4	80	15	300
2nd	n-1	0	0	3	57	4	76	5	95
3rd	n-2	0	0	2	36	3	54	1	18
4th	n-3	0	0	9	153	2	34	0	0
…20th	n-19	0	0	0	0	3	3	10	10
Total Borda count			144		356		326		500

Table 4 *Example of the expert borda count ranking*

Partner	Borda count	Type	Size	Expansion	Experience	Surge capacity
4	500	Military	Small	No	Low	Very high
5	427	Government	Small	Yes	Low	Low
2	356	Military	Small	Yes	Low	Medium
… 9	105	Government	Medium	No	High	Very high

7 CONCLUSION

The study was put forward to examine two hypotheses

The Hypothesis 1 inquired if 'The PREDIS model assists the decision-makers in making faster decisions'. Firstly, it was initially expected that the majority of the participants have their own decision model. The result shows that even the experts who have frameworks in place (two of them were described earlier) mostly rely on heuristics of trust, previous experiences, self-declared resources, and capabilities. Therefore, the conclusion can be drawn that in practice a specific numerical and measurable guideline, which can clearly compare various partners, is missing. Secondly, it was initially expected that the majority of the participants make their decisions under six hours (the golden hour) in order to be able to perform the initial rescue operations. The result shows that without the PREDIS model, 23% of the experts take less than one-hour to make decisions, 45% take between 1-6 hours to make decisions, and 32% take more than 12 hours to make a decision. However, using the PREDIS model all the participants could make their decision in less than an hour. This further confirms that the PREDIS model assist decision makers to make faster and comparable quality decisions

Hypothesis 2 inquired that *'The PREDIS model assists the non-experts in making decisions as well as experts'*. Interpreting the result shows that as far as the comparison of first and last choices of the experts and non-experts reveals, there is no evidence that by using the PREDIS model these two groups make the same choices. However, the Normalised Root Mean Squared Error (NRMSE) has been used to calculate a more precise percentage of error between the choices of the two groups. The NRMSE for difference between the two is calculated as 29% (Error between non-experts and experts) and 14% (Error between experts and non-experts). This means that although the first and last choice of the majority of decision makers in the two groups are not the same, between 71% and 86% of the times experts and non-experts decide similarly using the PREDIS framework. The significance of this result is that the non-expert does so with no prior training or data other than the data available through PREDIS model. Therefore, it is possible to conclude that although the result shows that the experts and non-experts may have various preferences, the model enables the non-experts to choose partners similarly to experts, if necessary.

The aim of this paper was to test the suitability of the PREDIS model for decision-making in the disaster situation Using two series of expert and non-expert participants, a hypothetical scenario of a previous disaster was re-played. The decisions the two groups made were recorded and compared. The results of the decisions show that the PREDIS model has two major capabilities. It enables the experts and non-experts to predict the disaster results immediately and using the widely available data. It also enables the non-experts to decide almost the same as the experts; either in predicting the human impact of the disaster and estimating the needs or in selecting suitable partners. It is also the only framework of its type, which takes specific numerical values as input, and provides specific numerical values and clear decisions as outputs such as which partners should supply how many units of the requirements.

However, there are some limitations associated with the PREDIS model. First, it is purely theoretical at the moment and has yet to be tested in a real disaster situation. Second, the data used for estimating the needs have been accumulated from various sources and their applicability in the actual disaster scenario might differ for each organization. Hence, further research is required to test the PREDIS model in a real disaster situation.

REFERENCES

Anand N Meijer D Duin J Van R and Tavasszy L (2013) Validation of an agent based model using a participatory simulation gaming approach : the case of city logistics Procedia - *Social and Behavioral Sciences* .

Barton R (1994) Metamodelinc;: A State Of The Art Review Proceedings of the 1994 Winter Simulation Conference (eds) J D Tew S Manivannan D A Sadowski and A F Seila.

Ben-zvi T (2010) The efficacy of business simulation games in creating Decision Support Systems : An experimental investigation *Decision Support Systems* 491 61–69 .

Colella V (2000) Participatory simulations: Building collaborative understanding through immersive dynamic modeling *The journal of the Learning Sciences* 94 471-500

Croson R Donohue K Katok E and Sterman J (2014) Order Stability in Supply Chains: Coordination Risk and the Role of Coordination Stock *Production and Operations Management* 232 176–196 .

Elgood C (1997) Handbook of Management Games and Simulation (6th edition) Gower Publishing Aldershot.

Gentile M Guardia D La Grande V D Ottaviano S Allegra M and La V U (2014) An Agent Based Approach to designing Serious Game : the PNPV case study Institute for Educational Technology - *National Research Council of Italy* **1(2).**

Keys B and Wolfe J (1990) The role of management games and simulations in education and research *Journal of Management* 16 307–36

Laine T Paranko J and Suomala P (2012)Using a business game concept to enhance servitization: a longitudinal case study *Managing Service Quality: An International Journal* **22(5)** : 428 - 446
Lewis M and Maylor H (2007) Game playing and operations management education International *Journal of Production Economics* **105(1)** 134–149.
Longworth J (1969) Management games and the teaching of farm management *Australian Journal of Agricultural and Resource Economics* 1358–67.
Longworth J (2008) From war-chess to farm management games *Canadian Journal of Agricultural Economics/ Revue Canadienne Dagroeconomie* 181–11.
Lopes M C Fialho F A P & Cunha C J C A (2013) *Simulation & Gaming* .
Madni A (2013) Game-Based Simulation for Cross-Cultural Decision Making Training Human Factors and Ergonomics *Manufacturing & Service Industries* **23(2):** 85–94.
Marchant Th (1996) Valued relations aggregation with the borda method *Journal of Multiple Criteria Analysis* 5:127–132
Mohan D Fischhoff B Farris C Switzer G E Rosengart M Yealy D Barnato A (2014) Validating a vignette-based instrument to study physician decision making in trauma triage Medical Decision Making : An International *Journal of the Society for Medical Decision Making* **34(2):** 242–52 .
Musshoff O (2011) Are Business Management Games a Suitable Tool for Analyzing the Boundedly Rational Behavior of Economic Agents? *Modern Economy* **02(04):** 468–478
Musshoff O and Hirschauer N (2014) Using business simulation games in regulatory impact analysis – the case of policies aimed at reducing nitrogen leaching *Applied Economics* **46(25):** 3049–3060
Norris D and Snyder C(1982) External Validation of Simulation Games *Simulation and Gaming* **13(1)** :73–85
Oderanti F O and De Wilde P (2010) Dynamics of business games with management of fuzzy rules for decision making International *Journal of Production Economics* **12(81)** : 96–109
Reichlin L Mani N McArthur K Harris A Rajan N and Dacso C (2011) Assessing the Acceptability and Usability of an Interactive Serious Game in Aiding Treatment Decisions for Patients with Localized Prostate Cancer *Journal of Medical Internet Research* 131: e4 .
Simon H A 1961 Business games Business Horizon Spring 6–9
Sterman J Fiddaman T Franck T & Rooney-varga J N (2014) World Climate : A role-play simulation of global climate negotiations.
Tanner C 1975 A survey of students attitudes to methods of teaching farm management Australian *Journal of Agricultural and Resource Economics* 1952–62.
Thavikulwat P Chang J & Sanford D (2013) Mergers and acquisitions in a business game Simulation & Gaming **44(5)** 706-731.
Thompson PA and Marchant EW (1995) Computer and fluid modelling of evacuation *Saf Sci* **18(4):** 277-289
Villamor G Troitzsch Klaus and van Noordwijk M (2013)Validating human decision making in an agent-based land-use model *Proceedings of the 20th International Congress on Modelling and Simulation Adelaide Australia.*

AUTHOR BIOGRAPHIES

SARA HASANI is a lecturer in Business Systems in Bedfordshire university and a member of UCL Institute for risk and disaster reduction (IRDR) and Operational Research Soceity. Her research focuses on various aspects of operations research, decision support system, risk management and serious games in the context of disaster management with the focus on segregation between short term and long term collaborative networks.

EMEL AKTAS is a senior lecturer in logistics and supply chain management in Cranfield University, School of Management and a member of the Operational Research Society. Emel's applied research is informed by mathematical modelling, simulation and optimisation to develop decision support systems for policy and decision makers on decisions at strategic, tactical and operational levels. Her current research focuses on decision making at operational level in the context of manufacturing, supply chains, and humanitarian logistics.