# Agent Based Simulation and Visualisation of Emergency Relief Effort Strategies

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**Abstract**

Prescriptive Analytics is an important branch of a key decision making process. One application of Prescriptive Analytics is combining agent based simulation, visualisation and subject matter opinion in order to evaluate and interrogate complex strategies. This paper considers the evaluation of military strategic responses to emergency relief efforts. Despite the good will of foreign governments offering military assets in crisis situations, their invention may often be subject to scrutiny, scepticism and criticism, citing expense and efficiency as questionable factors in the military involvement. As well as this, despite the human tragedy most governments would find it challenging to support a long term inefficient and expensive emergency relief effort. Nevertheless through prescriptive analytics, it is possible for the various experts to rehearse scenarios and develop a number of cost effective strategies. In this paper, we consider the theoretical scenario of an outbreak of a contagious virus similar to Ebola, across Europe, where an immunisation drug must be delivered to 50 of the largest EU cities. In order to address this, an agent based simulation version of the Vehicle Routing Problem with Time Constraints was developed. The outputs of this simulation were imported into the geographical interactive visualisation software Conduce.

## 1. Introduction

According to Hofmann & Hudson (2009) while the involvement of the military in relief operations is not new; consider the coalition of UK US and Canadian air forces involved in the 1948-49 Berlin. Nevertheless, Hofmann & Hudson (2009) argues that airlift activities have grown since the early 1990s; military resources were used in response to the 1991 cyclone in Bangladesh, and after Hurricane Mitch in Central America in 1998.

More recently, the US military support for hurricane Katrina in 2005. The deployment and intervention of UK troops directly securing infrastructure and in the support of civilian populous and huge numbers of Chinese troops deployed in the aftermath of the 7.9$M_w$ earthquake in Sichuan province in 2008. Following the October 2005 7.6$M_w$ earthquake in Pakistan, domestic and international military agencies mounted the one of the largest humanitarian helicopter airlift in history.

The development of strategic regional alliances is also playing a growing role in the operational sphere and future expenditure of military alliances. For example, in reaction to the tsunami, NATO is currently growing a humanitarian role in disaster response. There are numerous factors driving interest in the current, future and the evolving role of the military capability and its ability to respond to disasters; assisting relief efforts can improve the military's image and provide training opportunities and may also be a way for the military to diversify their role at a time when armed forces globally are experiencing budget cuts.

Hofmann & Hudson (2009), further argue that with an increase in the incidence of natural disasters, national and foreign militaries can be expected to play a larger role – particularly in large-scale disasters, where the capacity of humanitarian organisations may be stretched; Humanitarian agencies view these developments with a wary eye. In the US, the Non-Government Organisation (NGO) consortium InterAction has raised concerns about the newly established US Command for Africa (AFRICOM), whose tasks include supporting humanitarian assistance. Growing interest within the European Union in deploying civil defence and military assets outside EU territory has prompted similar concerns.

Critics of the military's involvement in relief claim that it is inefficient and expensive. Furthermore, according to the Oslo Guideline (2007), an Assisting State deciding to employ its Military and Civil Defence Asset (MCDA) should bear in mind the cost/benefit ratio of such operations as compared to other alternatives, if available. In principle, the costs involved in using MCDA on disaster relief missions abroad should be covered by funds other than those available for international development activities. Costs responsibilities, oversight and revenue sources are the subject to frequent debate. Deploying a military asset is, generally speaking, more expensive than deploying a civilian asset that offers an equivalent capability. The Oslo Guidelines clearly state that foreign military assets should be made available at no cost to the affected country, unless there has been prior agreement paragraph 27 (Ocho 2007), and this principle seems to have been applied in practice. However, the question remains who in the contributing country should bear the additional cost of deploying military assets questioning if they were deployed effectively (for the expense) based on the situational profile, context, primary and evolving objectives.

A number of Charity Aid organisations have objections, on both practical and ethical grounds, to the idea of military expenses being funded from humanitarian aid budgets. For example, the response to the 2004 Indian Ocean tsunami became a watershed for the UK Government in terms of how it budgets for deployment of military assets in a disaster relief zones Hofmann & Hudson (2009). During the relief operation following floods and cyclones in Mozambique in 2000, the UK made substantial contributions of six helicopters.

Historically there has been minimal discussion planning or foresight defining who would pay for each deployment, and the Ministry of Defence subsequently requested reimbursement from Department for International Development (DfID) for the bulk of the costs incurred ($14.37 million). To avoid a similar situation, before deploying military assets to tsunami relief operations, DfID and the Ministry of Defence drew up a Memorandum of Understanding (MOU) setting out cost-sharing arrangements. DfID paid only 30 per cent of the $7.42 million total cost of deploying military assets for tsunami relief. In the relief operation in Pakistan following the 2005 earthquake, DfID covered 49 per cent of the $6.7 million total military deployment costs. In both cases, the Ministry of Defence covered the remainder.

Nevertheless despite the arguments about cost when a disaster strikes, certain assets are needed urgently in the surge phase of the relief operation (peak time of arrival of military assets); if they do not arrive and become operational within a matter of hours or, at most, days, the opportunity to use them effectively is missed. Other assets may not be as critically needed or are required at a different stage of the operation. In such cases, timeliness depends on whether they become operational at the time that they are needed. For many, timeliness is perhaps the overriding reason for deploying military assets. According to a report for the OECD DAC, 'When large numbers of lives are immediately at risk, issues of experience, cost-effectiveness, and longer-term impact have to take secondary importance.'

As well as this, rapid-onset natural disasters often occur with little or no notice and call for an immediate response in order to prevent further damage or loss of life. This is particularly true in the case of earthquakes: search-and-rescue assets are most needed in the first 48–72 hours, when there is the best chance of saving the lives of people trapped in the rubble. It is generally recognized that one of the biggest comparative advantages of military assets in disaster response is that they are typically on permanent standby, available in large numbers, ready to deploy at a moment's notice, and thus able to reach the scene of a disaster quickly.

In terms of the Oslo Guidelines, military assets often have a 'unique availability' during the surge phase of a disaster response. Hence, the key examination question is how can the military respond to a natural disaster using a strategy that is efficient and inexpensive? A viable approach is to rehearse scenarios in order to develop strategies by means of Prescriptive analytics most notably numerical simulation and visualisation. One of the strengths of this approach is where there are a number of conflicting key performance indictors to optimise, it is easier with numerical simulation and visualisation to gain buy in from the stakeholders as they are embedded in the simulation development, assumption gathering and decision making process.

## 2. The Theoretical Problem

Given the spread of an Ebola like disease across Europe, there is a need to distribute immunisation drugs to 50 of the largest cities in EU. The military of a foreign government has agreed to air drop enough supplies that can cater up to 0.1% of the respected population size. The supplies will be delivered to up to three different locations. Given a finite number of air resources available, what is the best strategy in distributing the immunisation drug which is efficient and inexpensive?

Efficiency is defined as maximise the number of immunisation drugs delivered in the minimum amount of time. Inexpensive will be defined as minimise fuel consumption and the related distance travelled. For this problem, one of the following planes can be selected for the operation.

| Plane | Speed (km/h) | Range (km) | Fuel US gph |
|---|---|---|---|
| Aerospace ATP | 496 | 1825 | 132 |
| Antonov an-26 | 440 | 2500 | 127 |
| Hercules C-130 | 540 | 3800 | 1300 |

TABLE 1. Plane Specification

To demonstrate the capability three strategies will be evaluated; firstly the use of one plane based in a centralised location (Stuttgart), secondly the use of two planes one base in the extreme west (Malaga) the other at the extreme east (Riga) and finally, the use of three planes all based at the locations previously described. It is assumed that the foreign a non-European government will drop the immunisations at these locations. As well as this, once a plane lands it will take two hours before it takes off again. This is a variable within the simulation but for the purpose of this exercise will remain constant. The cost of hire of the planes and of fuel remains a further point for discussion and is not addressed directly here in this paper.

## 3. Agent Based Simulation and the Vehicle Routing Problem with Time Constraints

Babcock International Group has been developing an Agent Based Simulation with some assistance from Loughborough University -Zhang (2011). The Agent Based Simulation is based on the Vehicle Routing Problem (VRPWTC) (Tan 2001), initially used to aid Babcock's customer with Fleet management problems. The Agent Based Simulation has been evolved over the years and is now embedded within the Conduce Visualisation software.

For the Emergency Relief Effort the Agent Based Simulation will employ the following strategy, namely the plane which can reach the next city first, will be assigned the route to that city. This is as variation on the nearest neighbour principle -Zhang (2011) where instead of minimising distance, we are minimising time. This approach does, however produce a sub optimal routing solution but it is fit for purpose approach as many strategies can be investigated, especially in a real life situation of an actual emergency. The mathematical algorithm embedded within the agent based simulation is a follows;

Initialisation:

1. *List all the cities that to be visited $C_i$ where i is the city identity number.*
2. *Choose the number and types of planes $P_j$ where j is the plane identity number.*
3. *Choose base location for each plane $B_j$ where j corresponds to the plane identity.*
4. *Define $R_j$ as the maximum range of $P_j$ from the base $B_j$*
5. *Define $L_j$ as the plane $P_j$ current location. This will be either the city the plane is located or the city it is travelling to. We assume once a plane has taken off it is committed to its destination.*
6. *Define $ETD_j$ as the Estimated Time of Departure of $P_j$ from$L_j$.*
7. *Define $ETA_{ij}$ as the Estimated Time of Arrival of $P_j$ from $L_j$ to $C_i$.*

*Conditional:*

8. *Find the* $min[ETA_{ij}]$ *for* $\forall$ $i, j$ *which is satisfied by* $i = i^*$ , $j = j^*$ *and range is <* $R_j$
9. *If step 8 conditions are true, send* $P_{j^*}$ *from* $L_{j^*}$ *to* $C_{i^*}$.
10. *If step 8 conditions are true, update* $ETD_{j^*}$*and* $L_{j^*}$.
11. *If step 8 conditions are true, remove* $C_{i^*}$ *from the list of cities to be visited*
12. *If step 8 conditions are true, update* $ETA_{ij}$ *because of* $P_j$ *new location and* $C_{i^*}$*no longer needs to be visited.*
13. *If all the remaining cities are out of range of* $P_j$ *return plane to* $B_j$ *then update* $ETA_{ij}$, $ETD_j$ *and* $L_j$.
14. *Repeat steps 7 to 13 until all cities have been visited or the range >* $R_j$ *when* $P_j$*is located at base* $B_j$ *for* $\forall$ $j$.
15. *End of simulation.*

## 4. Results

Figures 1 to 3 are examples of data from a simulation of proposed strategies one to three respectively. Each dot indicates cities denoting latitude and longitude. Each light dot indicates the initial take off location routes selected are chosen from on the next city the planes are able to reach in the shortest time. This process becomes an exponentially more important factor for each new plane involved in the emergency relief effort.

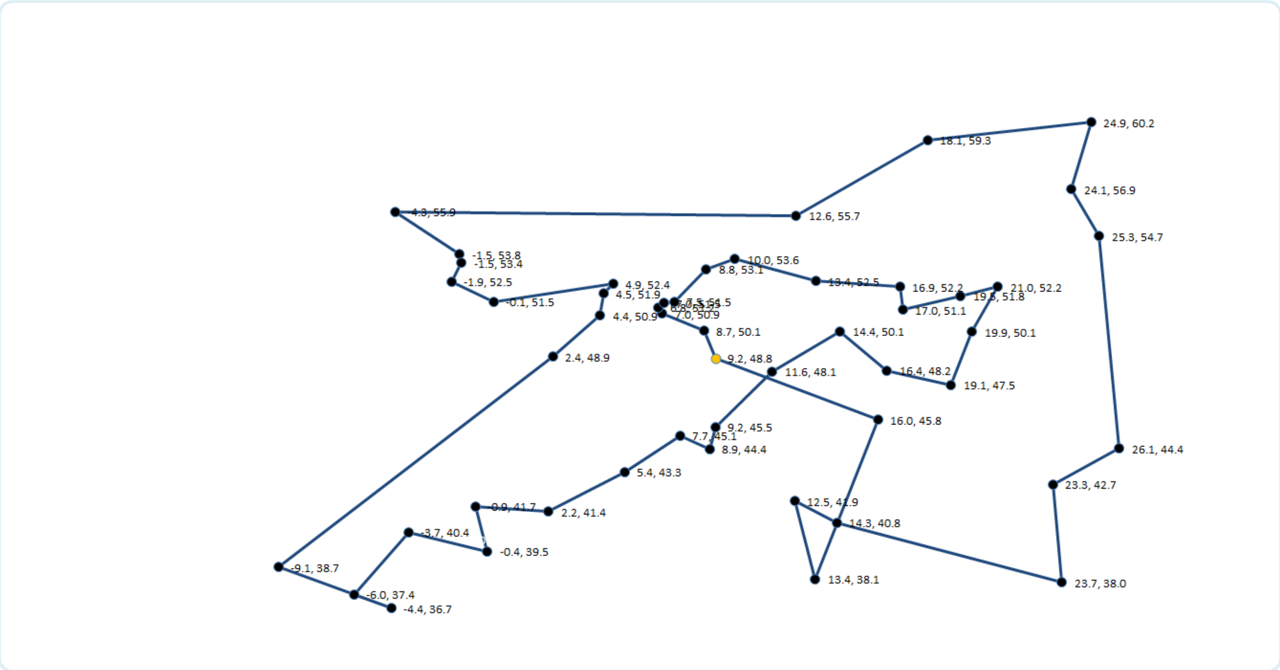


FIGURE 1. Strategy One - One plane: Hercules C-130 flying from Stuttgart.

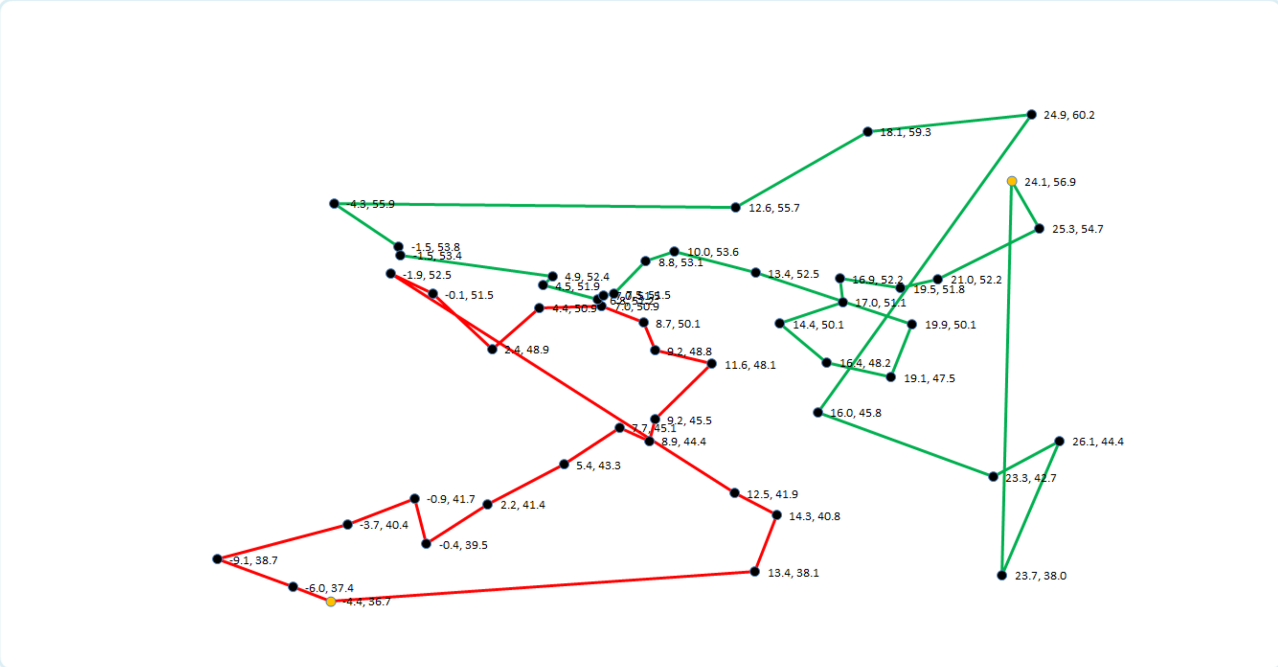


FIGURE 2. Strategy Two – Two Planes: Aerospace ATP flying from Malaga and an Antonov an-26 flying from Riga

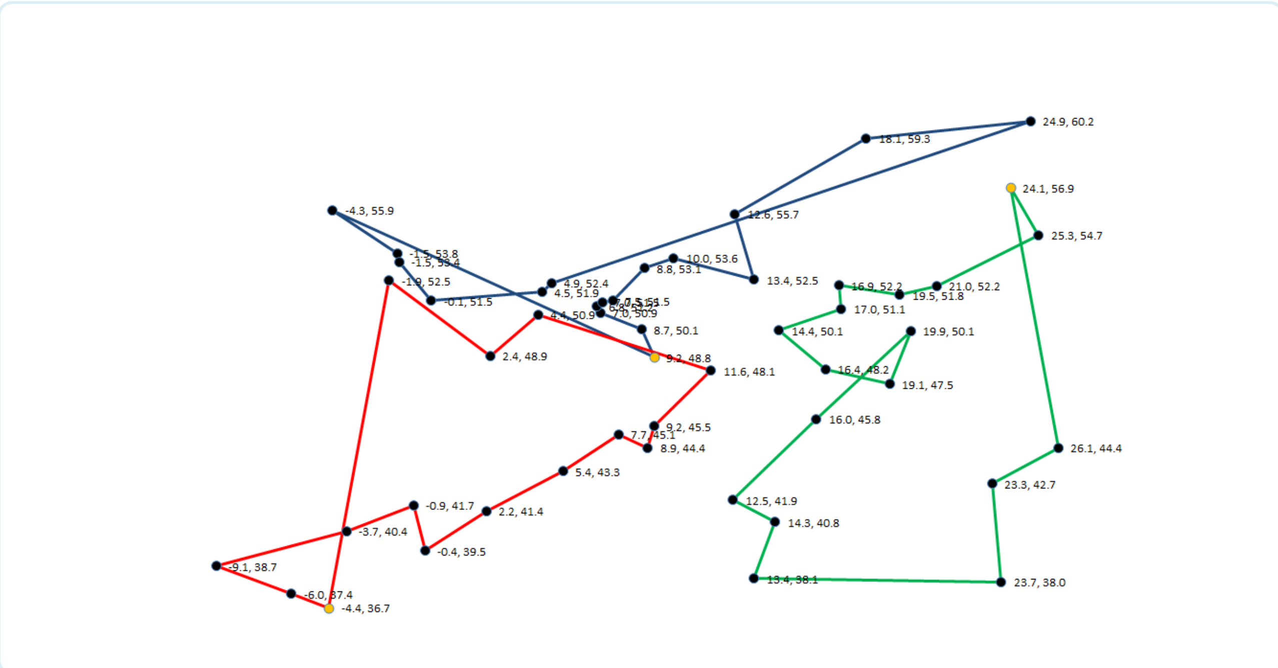


FIGURE 3. Strategy Three - Three planes: Hercules C-130 flying from Stuttgart, Aerospace ATP flying from Malaga and an Antonov an-26 flying from Riga.

For each city, the number of immunisation drugs delivered will be 0.1% of its respected population size. We will define each immunisation drug delivered as an order. Table 2 gives a summary of the performance of each the simulated strategies.

| | Strategy 1 | Strategy 2 | Strategy 3 |
|---|---|---|---|
| Number | 1 | 2 | 3 |
| Location | Stuttgart | Malaga | Stuttgart |
| | N/A | Riga | Malaga |
| | N/A | N/A | Riga |
| Planes | Hercules C-130 | Aerospace ATP | Hercules C-130 |
| | N/A | Antonov an-26 | Aerospace ATP |
| | N/A | N/A | Antonov an-26 |
| Actual Orders | 60641 | 60641 | 60641 |
| Distance (km) | 16336 | 19821 | 18750 |
| Fuel (US gph) | 39327.50 | 5538.41 | 17701.58 |
| Orders per km | 3.71 | 3.06 | 3.23 |
| Orders per US gph | 1.54 | 10.95 | 3.43 |

TABLE 2. Strategy Performance Statistics

As it can be seen in Table 2, strategy 1 returns the best orders per km. However, as seen in Table 1, because of the Hercules C-130 higher fuel consumption, it returns the worse missions fuel consumption and lowest order per US gph. Strategy 2 on the other hand has higher orders per US gph but never the less delivers less orders per km than strategy 1. Finally strategy 3, the three plane solution does not outperform either strategies 1 or 2 on any of the categories. Nevertheless, Figure 4 shows one key performance indicator that strategy three does perform well on; time.

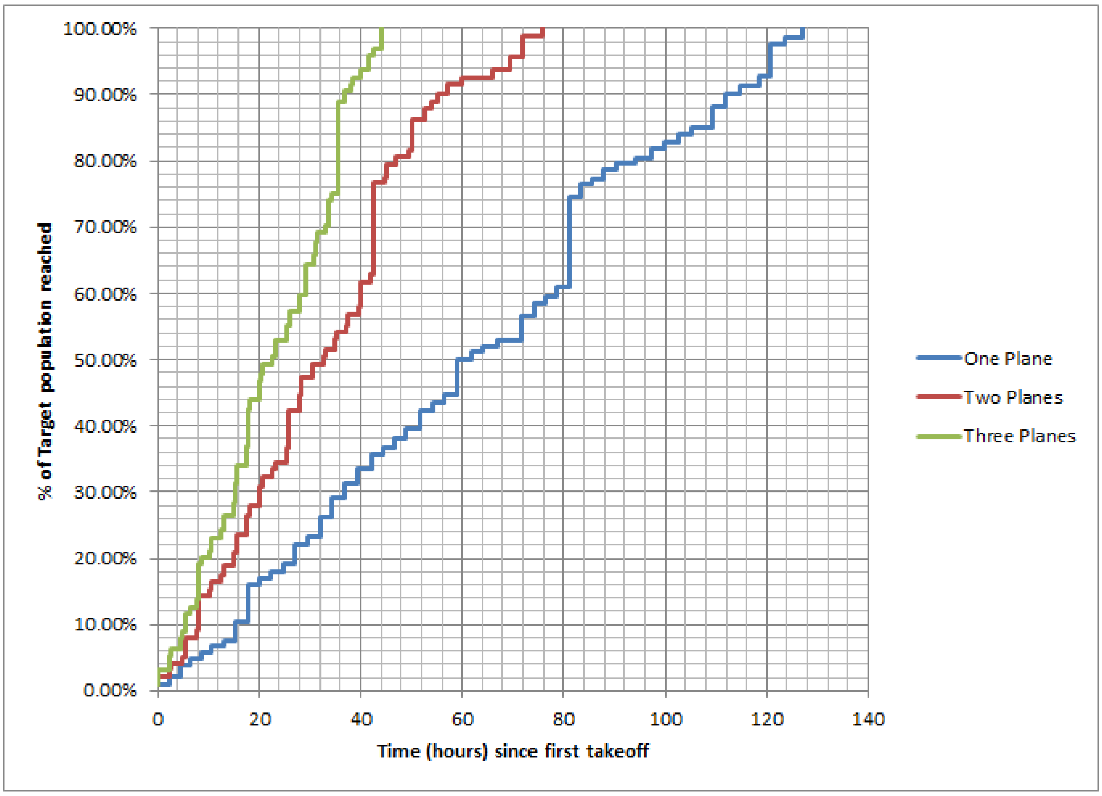


FIGURE 4. The percentage if target population reached since the deployment of the planes.

Assuming that each plane takes off at the same time, the last city to be reached; using strategy 1 is Zagreb after 127 hours, for strategy 2 its Athens after 76 hours while for strategy 3 it will be Bucharest after 44 hours. In terms of speed of distributing the immunisation drug, strategy 3 outperforms strategy 1 and 2. From these results each strategy has it positive and negative points. As well as this, there are other strategies that we could explore. For example, we could use different planes and also move the base location. Although it is possible to use optimisation or even a cost capability trade off model, we chose not to as this would involve putting a cost to an individual's life. Alternatively, we have chosen the approach where the simulation informs the debate as oppose to making the decision. As it can be seen in Table 2, strategy 1 has the advantage in terms of; only one plane deployed with it associated costs, distance travelled as well as the number of orders per km. However, as seen in Table 1, the Hercules C-130 has been allocated a high fuel consumption. This is reflected within the mission's fuel consumption and a low order per US gph.
In this case we have used the visualisation system Conduce. As stated before one of the strengths of this approach is where there are a number of conflicting key performance indictors to optimise, it is easier with numerical simulation and visualisation to gain buy in from the stakeholders as they engage within the simulation development, assumption gathering and decision making process, applying tacit, contemporary knowledge as part of further decision making and discussion.

## 5. CONDUCE

Conduce is used in this scenario to bridge the gap between the technical output produce by the simulation and the real world scenario to which it is being applied. Geographical representation presented allows stakeholders to immediately understand what the results of the scenario will look like when applied to the specific region. This opens up opportunity for informed debate between the stakeholders and the technical teams. Figure 5, shows a typical output from Conduce.

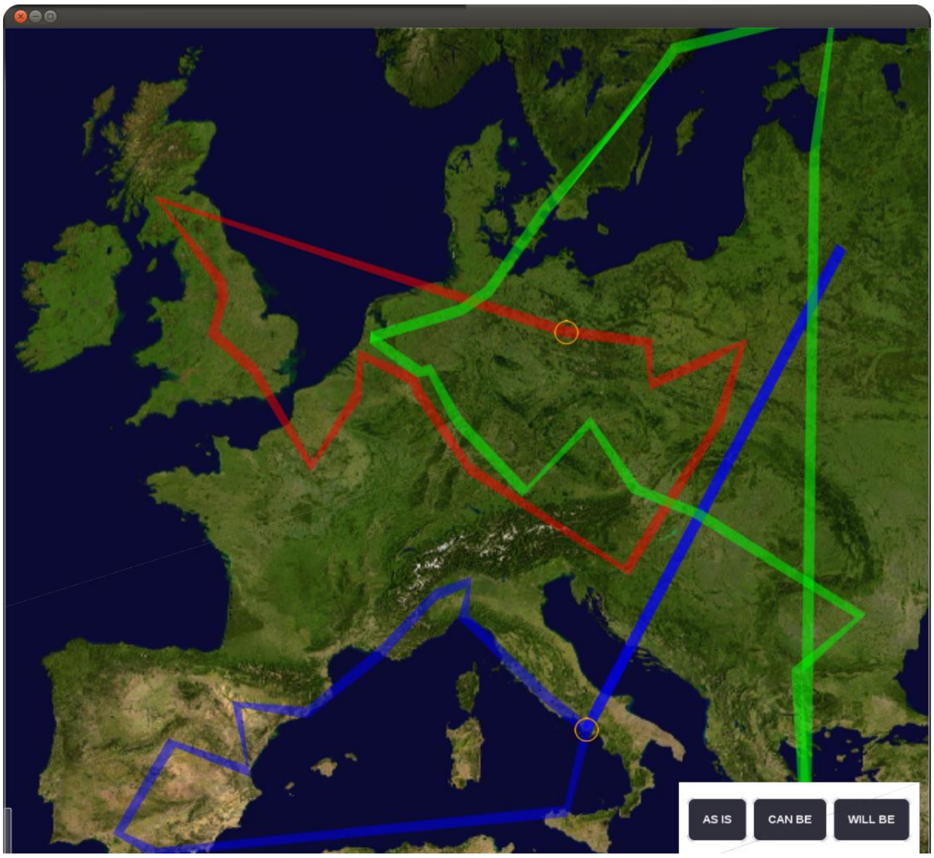


FIGURE 5. Visualisation of the VRPWTC problem using Conduce.

Conduce offers a familiar interface that allows stakeholders to tweak and re-run simulations, allowing for iterations of multiple scenarios, meaning that an optimal solution can be discovered rapidly. As well as this, this interface allows the stakeholders and the technical team to validate, verify, evaluate and interrogate the various emergency relief effort strategies. However even more important for a real life crisis, Conduce would be able to assess the live situation as it is developing and determine which strategy provides the best outcome.

FIGURE 6. Using Conduce to evaluate the performance statistics of each of the strategies.

## 6. CONCLUSION

One definition of Prescriptive Analytics maybe understood as being the combining of simulation, visualisation and subject matter opinion in order to evaluate and interrogate complex strategies. Despite the good will of stakeholders involved, the use of military assets in an emergency relief effort has been criticize as expensive and inefficient by some quarters. In this paper we describe an approach of rehearsing strategies for emergency relief efforts as well having the potential to aid in coordination in a real life crisis. One of the strengths of this approach is where there are a number of conflicting key performance indictors to optimise, it can be argued that it may be is easier with numerical simulation and visualisation to gain rational context and therefore buy in from the stakeholders as they are embedded in the simulation development, assumption gathering with recommendations for the wider decision making process.

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