Multi-Objective Decision Making for the Fire and Rescue Services – A Scoping Study

Dr. Alastair Clarke
Prof. John Miles
Prof. Yacine Rezgui

Cardiff School of Engineering
Multi-Objective Decision Making for the Fire & Rescue Service

Contents

• Introduction
• Problem scale
• Evolutionary Algorithms
• Software Development
• Conclusions and Future Work
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Introduction

• Strategic (long term) decision making for Fire and Rescue Service Resources
  – Fire Station location
  – Appliance location
  – Crewing types (wholetime or retained)
  – Specialised equipment locations
  – Response types

• Large problem

• Many potential solutions
Introduction

• Current tools available for strategic decision making
  – Fire Service Emergency Cover toolkit (software) FSEC
  – Measures effectiveness of a particular scenario based on life and property loss
  – Based on statistical incident data
  – Only allows user to evaluate one option at a time
  – Run-times are long (approximately 20-30 minutes for a typical FRS area)

• Is this a problem?
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Problem Scale

• Typical brigade – e.g. South Wales FRS
  – Approximately 50 stations
  – 19 wholetime, 5 day crewed, 26 retained
  – 1000 full time firefighters
  – 600 retained
Problem Scale

- Assuming 70 station sites (i.e. current 50 sites plus 20 potential sites)

- 50 stations to be placed in suitable locations – how many combinations of 50 stations can be selected from 70 sites?

\[ N_s = \binom{70}{50} = \frac{70!}{50!(70-50)!} \approx 10^{17} \]

- But each station can have a variety of configurations based on crewing type, vehicle allocation etc

- Conservative estimate would suggest 6 different station configurations
Each set of 50 stations can therefore be configured in $6^{50}$ ways ($\approx 10^{38}$)

Thus total configurations is

$$N = N_s \times N_c = 10^{17} \times 10^{38} = 10^{55}$$

Some of these configurations may not be feasible, or may include near-duplicates.

However, it is impossible to even evaluate 10% of the total number of solutions manually.

The only feasible way of finding good solutions is via the use of some form of search algorithm.

Evolutionary algorithms have been chosen for this work.
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Evolutionary Algorithms

• Bio-inspired search algorithms
  – e.g. Ant colony, particle swarm analysis, genetic algorithms

• Ideal for complex problems
  – do not require fully-defined objective function
  – use a “fitness function” as a means of judging whether one solution is better than another
  – avoid getting stuck on local optima
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Evolutionary Algorithms

- Genetic Algorithms chosen for this work
- Mimic Darwinian evolution (i.e. survival of the fittest)
- Starts with a population of random solutions
- Population gradually evolves by selection, breeding and mutation of the best solutions at each generation
- Only has to sample a small proportion of the total possible solutions
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Evolutionary Algorithms

• Genetic algorithm (GA) architecture

Create initial population

Assess current population fitness

Are the fitness criteria satisfied?

Stop

Selection

Crossover

Mutation

Genetic Operators
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Evolutionary Algorithms

- GA developed for this project
- Tested using simple fitness functions with known solutions
- e.g. maximise $\sin(x)$ where $0 < x < \pi$
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Software Development

• Need a measure of the suitability of potential solutions within the Genetic Algorithm

• A “fitness function”

• Based on methodology from existing software (FSEC)

• Fire Service Emergency Toolkit (FSEC)
  – Based on a Geographical Information System (Wings32)
  – Run-times very long – 27 minutes for a typical brigade
  – Very graphics-intensive
  – Manual model configuration
  – Unsuitable for direct use as fitness function
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Software Development

• FSEC
  – Includes geographical relationships of brigade area
  – Road network
  – Census data
  – Incident data
  – Fire station locations and vehicle / staffing allocations
  – Calculates likely rates of four types of incident
    • Dwellings fires
    • Special Services Incidents (e.g. road traffic incidents)
    • Other buildings fires
    • Major Incidents (e.g. terrorist attack, major rail accidents)
  – Calculates fatalities and property damage based on mathematical relationship between response times and losses
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Fire Station with vehicles
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- Dwellings
- Special Services
- Other Buildings
- Major Incidents

Statistical Incident Data
Output Area Data
Likely number of Fires or Casualties in Output Area for each incident type

Geographical Data
- Road Network
- Vehicle Data
- Arrival Times
- Fatalities
- Property Loss
Using FSEC as a fitness function
- Fitness function is evaluated multiple times within each generation of the genetic algorithm
- Need for significant reduction in execution times
- Core FSEC calculations re-programmed in Fortran
- Original FSEC used as pre-processor
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• Re-coded model achieves significant reduction in execution times:
  – Original full FSEC model for typical brigade 27 min
  – New Fortran FSEC code for same data 18 sec

• All configuration-specific calculations contained within Fortran code

• Pre-processor deals with statistical processing

• Time savings achieved for multiple runs – i.e. to evaluate 500 different resource configurations:
  – Original FSEC 227 hours
  – New Fortran FSEC 3 hours
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Software Development

Original FSEC Preprocessor → OB processing Input Manipulation

Vehicle / Station / Manning “Population” → Fast FSEC “Fitness”

Selection, Crossover, Mutation “Genetic Operators”

GENETIC ALGORITHM LOOP

Optimised Configuration
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Future Work

- Continue work to link Genetic Algorithm to Fortran FSEC
- Test and experimentation…..
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Conclusions

• Optimising Fire Service resources is a highly complex problem

• There are a massive number of potential solutions

• It is impossible to manually evaluate all solutions

• Evolutionary algorithms offer many advantages in dealing with complex problems such as this

• A computationally more efficient version of FSEC has been developed for use as a fitness function

• A Genetic Algorithm has been written

• Work is ongoing to couple the two
Multi-Objective Decision Making for the Fire & Rescue Service Project Website

http://fire.engineering.cf.ac.uk
Multi-Objective Decision Making for the Fire & Rescue Service

Acknowledgements