Fire Risk Management Conference 2010

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

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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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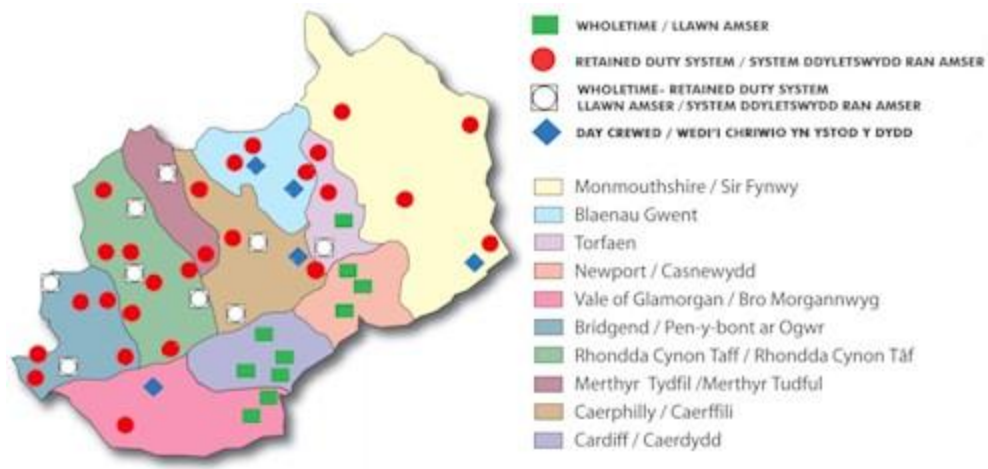
Problem Scale

- 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?

$$N_s = {}_{70}C_{50} = \frac{70!}{50!(70-50)!} \approx 10^{17}$$

- But each station can have a variety of configurations based on crewing type, vehicle allocation etc
- Conservative estimate would suggest 6 different station configurations

Problem Scale

- 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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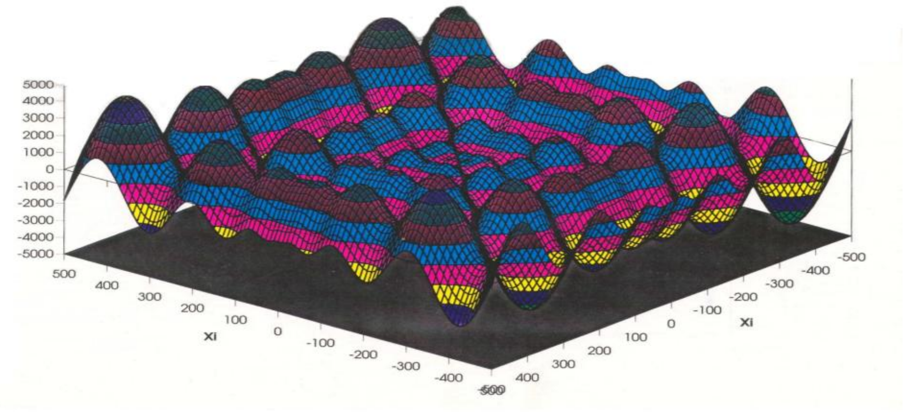
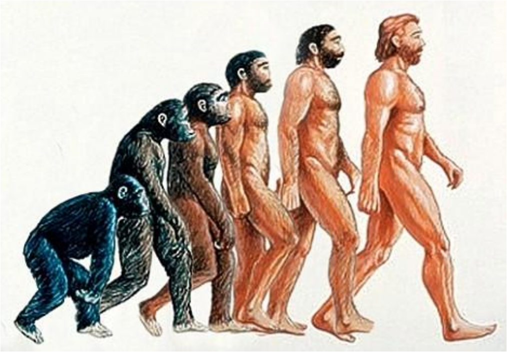
Evolutionary Algorithms

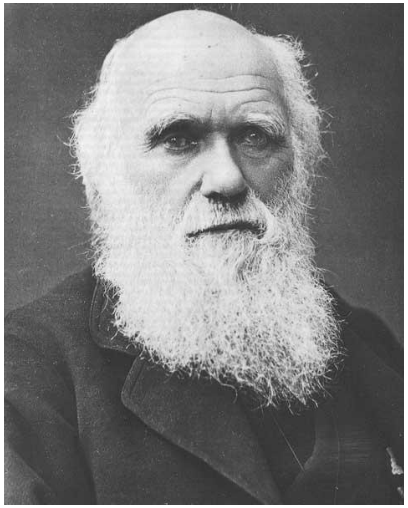
- Bio-inspired search algorithms
  - e.g. Ant colony, particle swarm analysis, genetic algorithms
- Ideal for complex problems
  - do not require fully-defined objective function
  - use a “fitness function” as a means of judging whether one solution is better than another
  - avoid getting stuck on local optima



Evolutionary Algorithms

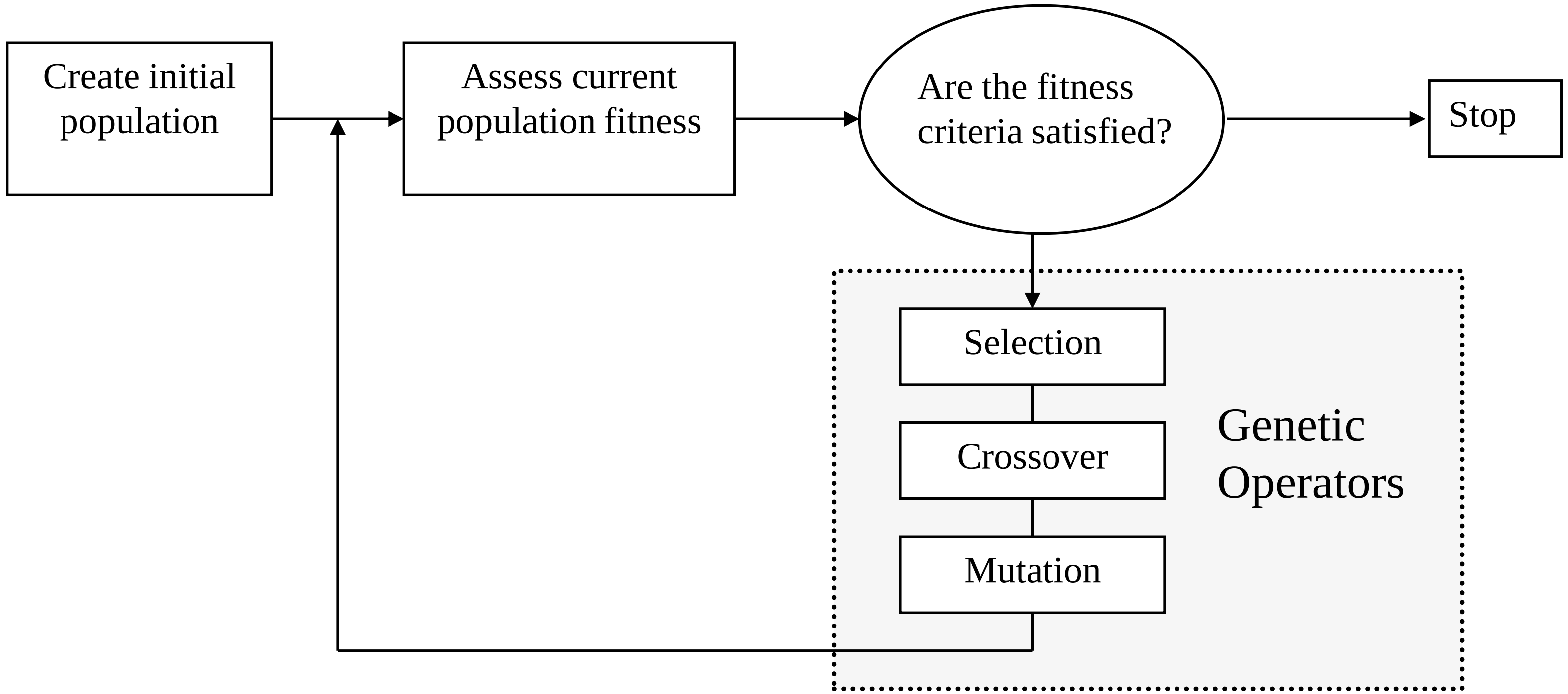
- Genetic Algorithms chosen for this work
- Mimic Darwinian evolution (i.e. survival of the fittest)
- Starts with a population of random solutions
- Population gradually evolves by selection, breeding and mutation of the best solutions at each generation
- Only has to sample a small proportion of the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





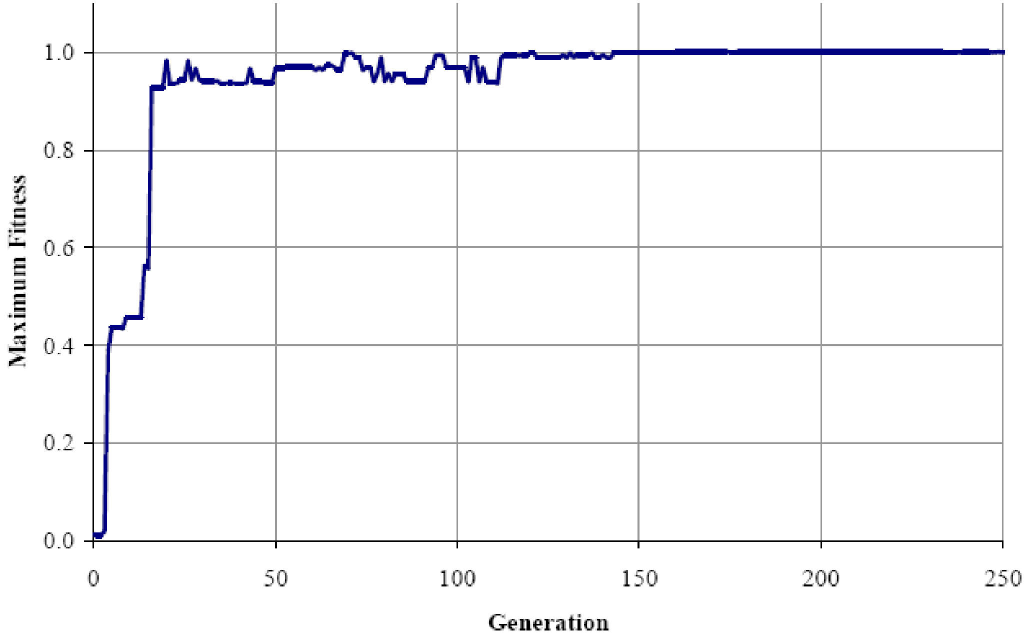
Evolutionary Algorithms

- Genetic algorithm (GA) architecture



Evolutionary Algorithms

- GA developed for this project
- Tested using simple fitness functions with known solutions
- e.g. maximise sin(*x*) where 0 < *x* < π



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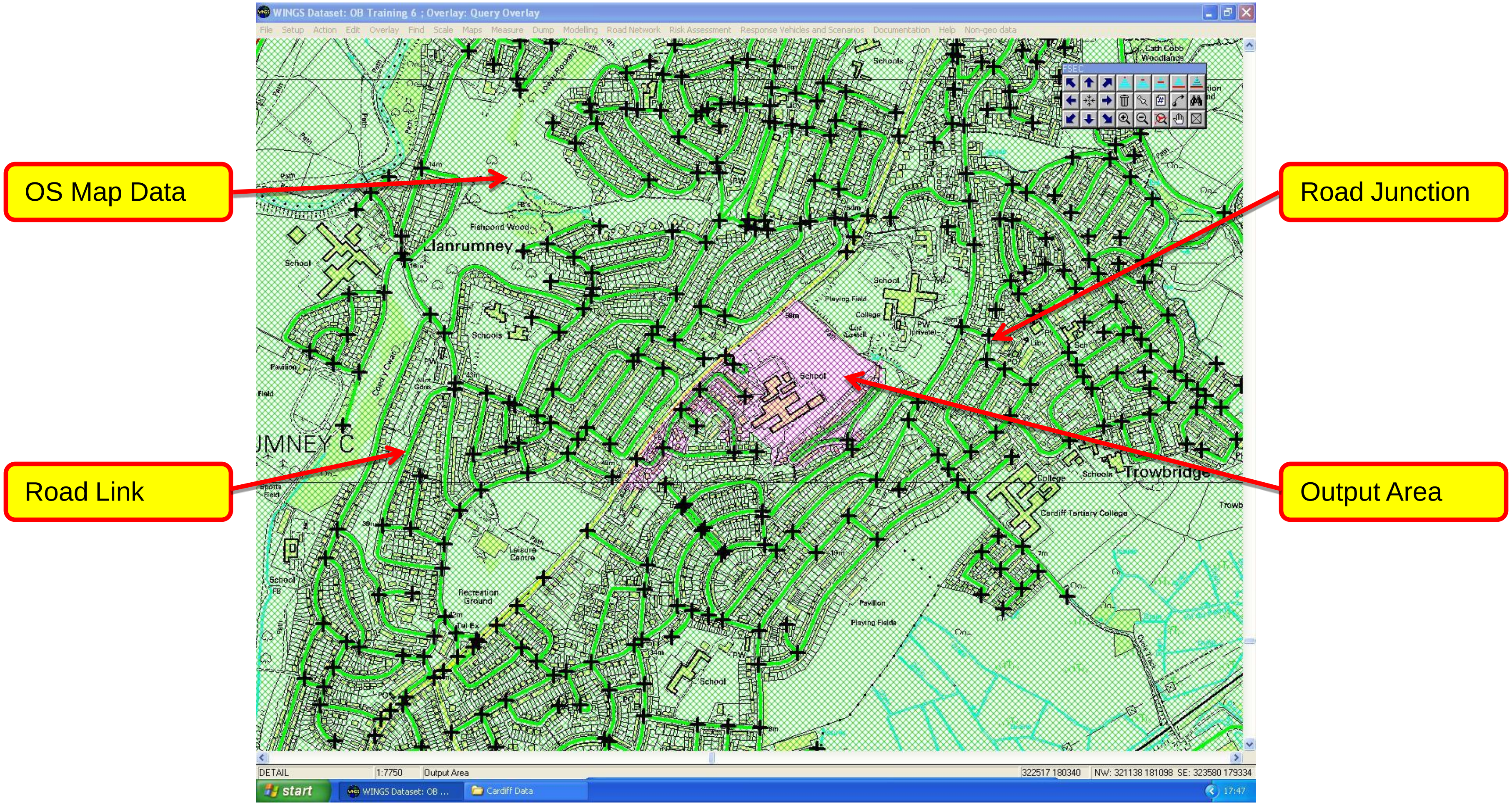
Software Development

- 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

Software Development

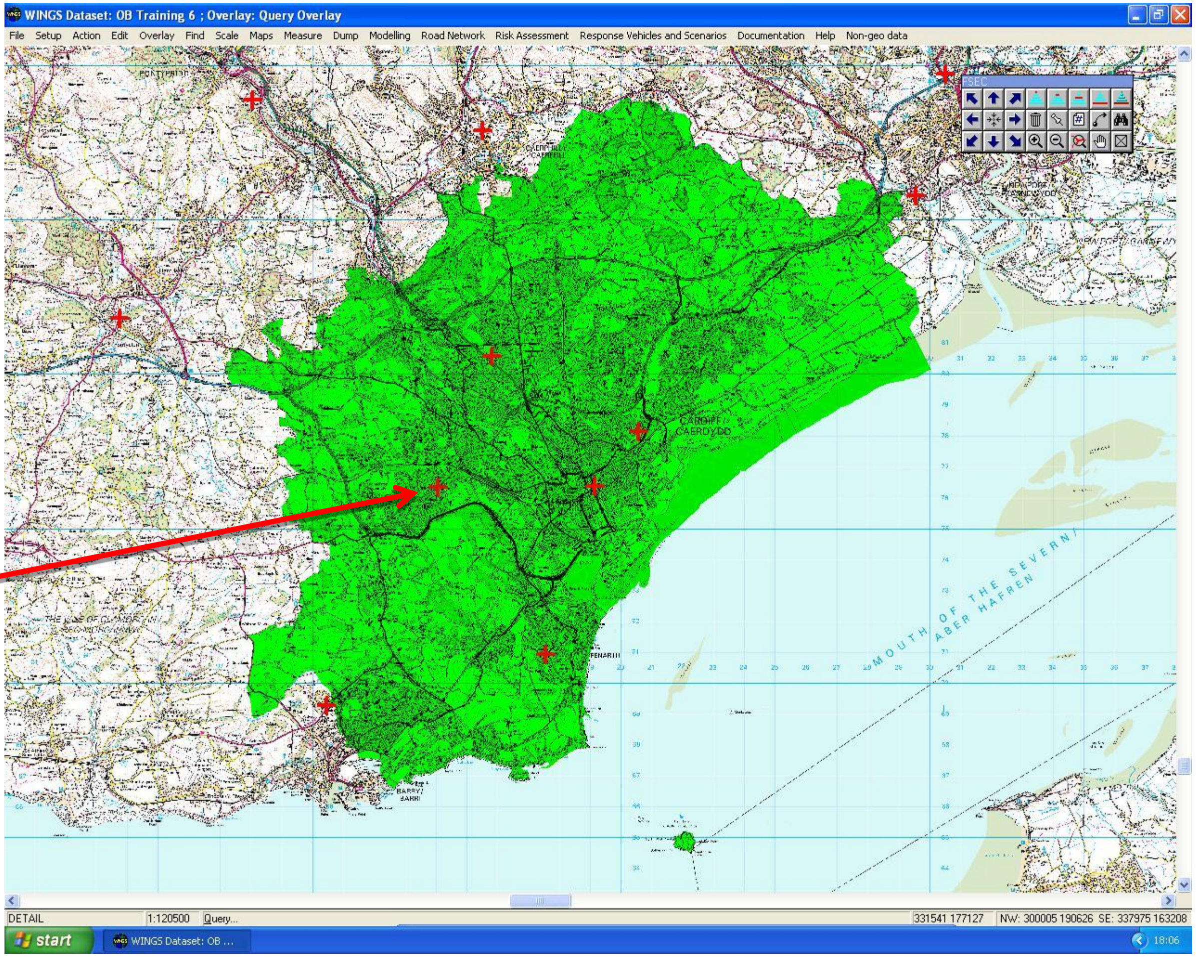
- FSEC
  - Includes geographical relationships of brigade area
  - Road network
  - Census data
  - Incident data
  - Fire station locations and vehicle / staffing allocations
  - Calculates likely rates of four types of incident
    - Dwellings fires
    - Special Services Incidents (e.g. road traffic 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

Software Development



Multi-Objective Decision Making for the Fire & Rescue Service

Software Development



Fire Station with vehicles

Multi-Objective Decision Making for the Fire & Rescue Service

Software Development

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

Software Development

- 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

FSEC Toolkit

Pre-Processor

Incident risk statistical calculations

→

Fortran code

Pre-Processor
Other Buildings manipulation

Core model
Resource configuration
Arrival times
Loss calculations

→

Outputs

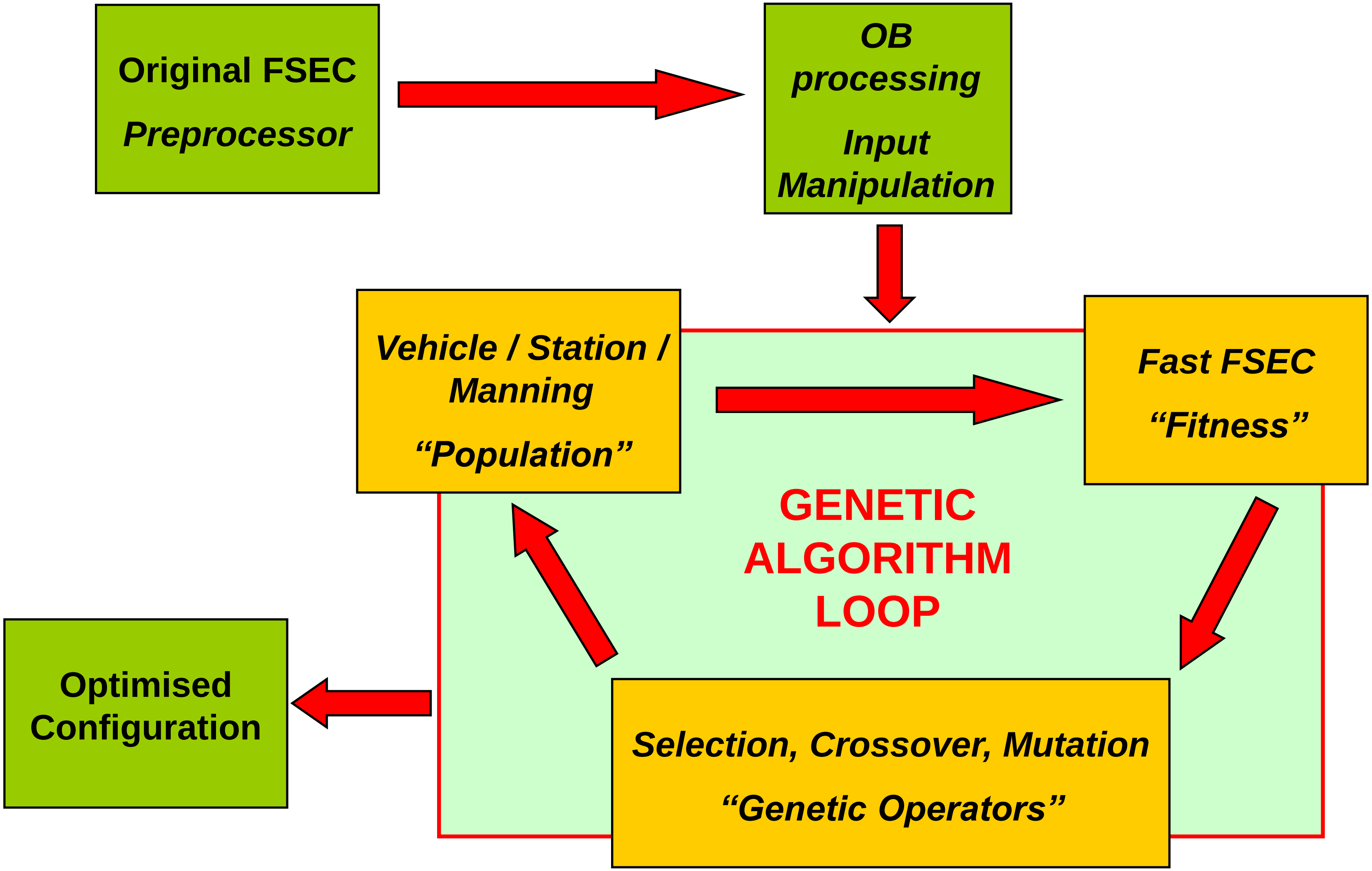
Fatalities

Property Damage

Software Development

- 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

Software Development



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

Future Work

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

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

Project Website

http://fire.engineering.cf.ac.uk

Acknowledgements

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