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The allocation of tanker aircraft to meet a stated requirement

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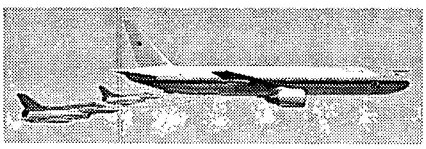
Background

- Work completed for the FUTURE STRATEGIC TANKER AIRCRAFT (FSTA) bid team.
- Conducted within the Integrated Defence Analysis Team (IDAT) of Future Systems. Part of BAE SYSTEMS.
- BAE SYSTEMS part of Tanker & Transport Service Co Ltd (with Boeing, Serco and Spectrum Capital)



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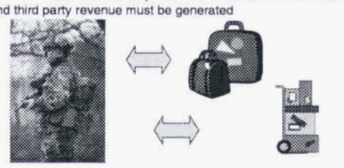
What is this presentation about?

- Provide a description of the tanking problem.
- Explain why this problem is different from others.
- Examine some techniques that were considered to solve problem.
- Describe the solution methodology.
- Provide example of results.

Why has this route been selected?

- Insufficient budget for traditional purchase
- Part of UK MOD Smart Acquisition: Public Private Partnership (PPP) / Private Finance Initiative (PFI)
- PPP / PFI? In simple terms, in the military context, Industry buys capability and provides service to Customer (RAF / MOD)
- Terms of PPP / PFI mean that the only income can not be from service to Customer and third party revenue must be generated



Why is this good?

- PPP / PFI good for Customer:
  - –No large capital outlay
  - –Value guaranteed by Public Sector Comparitor (i.e. better value to the government)
- PPP / PFI good for Industry Supplier:
  - –guaranteed income stream over number of years (~£13B, 25 years)
  - –potential for export
  - –income from third parties
  - –extension of Industry capability into new market areas

What is the problem?

- BAE SYSTEMS needs to operate in different conditions:
  - –previously act as a supplier (i.e. UK MOD completes analysis and asks for a number of aircraft)
  - –now act as a service provider (i.e. UK MOD states demand and we have to determine how to meet it)
- Given demand:
  - –How many tanker aircraft do the RAF need?
  - –Minimise cost to Supplier. (Assets not being used is a waste of money)
  - –Minimise asset cost. (Improve competitiveness of bid)

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What do we know?

- Refuelling events (20 days of operations)
  - day
  - time window (six 4 hour intervals each day)
  - sequence (order maintained at Low Level Entry Point (LLEP))
  - location (i.e. towline)
  - fuel delivered (out and back)
- Duration of each leg (e.g. time to top of climb, from TOC to AAR towline, from towline to LLEP, etc.)
- Aircraft characteristics
  - fuel usage rates
  - refuelling capability
  - amount of fuel carried
- Constraints on system
  - flying hours (crew not fuel limited)
  - on station coverage
- Need to minimise number of aircraft and show associated flying schedule

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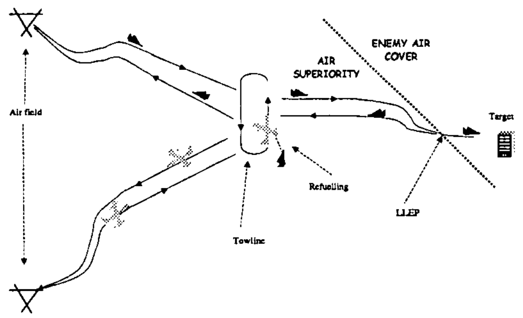
The situation



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Why is this problem different?

- References found to 'standard problems':
  - Multiple depot vehicle scheduling problems
  - Length of path constrained problems
  - Crew scheduling for mass transit problem
  - Aeroplane and aircrew scheduling problem
  - School bus routing and scheduling
- No methodology found in literature
  - Sequencing (bus routing)
  - Time windows
  - Diminishing resource (fuel)
- Need to find our own solution methodology

Reference: Bodin & Golden, "*Classification in vehicle routing and scheduling*", Networks, Volume 11, 1981

Approaches considered

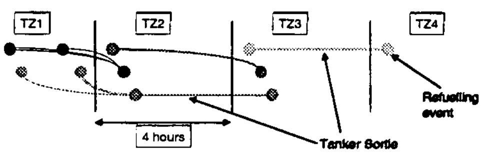
	Sortie	Time windows	Sequencing	Towline changes	Overall
Linear programming	✓	✓	✓	×	×
Non-linear programming	✓	✓	✓	×	×
AI techniques	✓	✓	✓	✓	×
Simulation	✓	✓	✓	✓	×
Interactive spreadsheet	✓	✓	✓	✓	✓

Simulation - stochastic

- Randomly allocate refuelling time within time window
- Determine how many refuelling aircraft would be required
- Use Monte Carlo approach to repeat
- Problem: How do we know that the answer is the best possible?

Simulation - deterministic

- Algorithmic grouping of refuelling events into sorties
- Algorithmic allocation of sorties to tanker
- Problems arise when it become necessary to move refuelling events



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Interactive spreadsheet

- Basis was a simple spreadsheet calculator
- User enters data
- Integrated error checking
- Automated calculation of minimum number of aircraft

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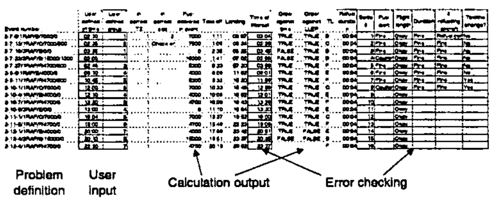
Interactive spreadsheet - input



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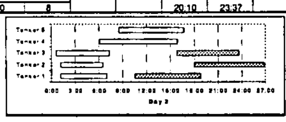
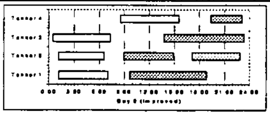
Example

Events	Sortie grouping	Aircraft number	Take off	Refuel	Land	Fuel used (kg)	Available next
2-7-6/1RAF/B/7000/0	1	1	1:11	2:30		50240	
2-7-16/3RAF/B/0/0	1			3:35			
2-7-23/2RAF/B/15000/1300	1			3:00	07:02		
2-7-13/1RAF/C/7000/500	2	2	1:06	2:35	06:34	33124	
2-7-27/1RAF/F/4700/600	3	3	0:33	2:45	07:20	38570	
2-9-6/1RAF/E/4000/0	4	4	6:09	8:10		53324	17:54
2-10-4/1RAF/E/4000/0	4			12:10			
2-10-6/3RAF/E/0/0	4			13:00	15:54		
2-9-11/1RAF/F/4700/600	5	5	8:33	10.45		49067	16:43
2-10-7/1RAF/F/4700/0	5			12:20	16:43		
2-10-1/1RAF/C/7000/0	6	1	10:33	12:00		51661	20:52
2-11-1/1RAF/C/7000/0	6			15:04	18:52		
2-12-1/1RAF/E/4000/0	7	2	17:59	20:00		50234	*04:52*
2-12-4/1RAF/F/4700/0	7			22:30	*02:52*		
2-11-5/1RAF/F/4700/0	8	3	15:46	18:00		56141	*01:37*
2-12-4/2RAF/B/15000/0	8			20:10	23:37		

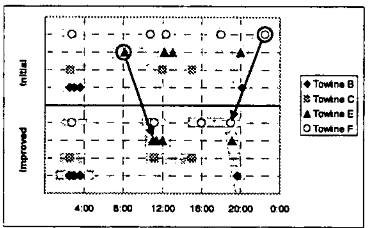


Example - improved

Events	Sortie grouping	Aircraft number	Take off	Refuel	Land	Fuel used (kg)	Available next
2-7-6/1RAF/B/7000/0	1	1	1:11	2:30		60240	
2-7-16/3RAF/B/0/0	1			3:35			
2-7-23/2RAF/B/15000/1300	1			3:00	07:02		
2-7-13/1RAF/C/7000/500	2	2	1:08	2:35	06:34	33124	
2-7-27/1RAF/F/4700/600	3	3	0:33	2:45	07:20	38570	
2-9-6/1RAF/E/4000/0	4	2	8:59	11:00		37793	
2-10-4/1RAF/E/4000/0	4			11:20			
2-10-6/3RAF/E/0/0	4			12:00	14:54		
2-9-11/1RAF/F/4700/600	5	4	8:33	10:45		44167	
2-10-7/1RAF/F/4700/0	5			11:10	15:33		
2-10-1/1RAF/C/7000/0	6	1	9:43	11:10		55181	20:52
2-11-1/1RAF/C/7000/0	6			16:04	18:52		
2-11-5/1RAF/F/4700/0	7	3	13:48	16:00		54389	*01:22*
2-12-4/1RAF/F/4700/0	7			19:00	23:22		
2-12-1/1RAF/E/4000/0	8	2	17:09	19:10	22:52	32393	*00:52*
2-12-4/2RAF/B/15000/0	9	4	18:23	19:42	23:09	37426	*01:09*



Clearer display



Conclusions

- Heuristic approach to find number of aircraft
- Local minimum
- Uncertainty of global minimum, relies on experience
- Time saving, good comparison with hand calculations