SUSTAINABLE DESIGN OF FORWARD OPERATING BASES
Sustainable Forward Operating Bases 2012
London Hilton Olympia, 20th-21st March

Work originally presented at the 6th IEEE Intl Conf. on System-of-Systems Engineering, SoSE 2011, Albuquerque NM

G Cave, W Goodwin, M Harrison, A Sadiq and T Tryfonas
Outline

• Background and motivation
• Key facts
• Requirements and design concepts
• Simulation evaluations
• Conclusions and challenges
Background and motivation

Industrial Doctorate Centre in Systems

- Engineering doctorate programme in Systems at Bristol
  - £8M+ EPSRC sponsored (2007-2017), 70+ research students funded to today, first graduations last summer
  - 30+ industrial sponsors
  - Wide range of domains: civil, aero, mech, comp sci, elec eng
  - With applications in defence, nuclear, safety, sustainability, manufacturing, automotive, IT, …
Background and motivation

- The idea for this paper came from attending SoSE 2010 (Loughborough, UK)
- Discussed with industrial liaison the possibility of exploring the efficiency of some design concepts via postgraduate student work
- The resulting work was originally presented at SoSE 2011 last summer (Albuquerque, US)
Key facts

• FOB inwards supply chain footprint:
  – 50% fuel supply
  – 30% water
  – 20% various

• Removal of waste another potentially sizeable task
Key facts

- Protection accounts for as much as 90% of the fully burdened cost of fuel.
- 3% of the total amount of fuel in Afghanistan represents 25% of the entire fuel costs.

Legend:
- Force Protection
- Purchase cost of diesel
- Moving and storing fuel
Key facts

• Several initiatives to deliver more sustainable bases, e.g.
  – Capability Vision of a Self-Sustaining Forward Operating Base, UK MoD
  – Green Warrior Implementation Strategy, US DoD
Typical deployment

- Semi-permanent or temp structures
  - B-huts and/or tents
- Larger establishments may include MWR facilities adding to the baseline power requirements
- US usually higher demands from UK equivalent
  - Typical UK req for 100 men: 17 kW
  - US guidelines:
    - ‘1kW of peak demand per person’
    - ‘company size FOB will require 1000kWh of electric energy per day’ (US Navy source)
An unsustainable FOB
<table>
<thead>
<tr>
<th>Stakeholder</th>
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### Stakeholder Requirements Analysis

Table 1. Sustainable FOB Stakeholder Analysis

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Approaching the requirements under a 3Rs philosophy
Design rationale

HOLISTIC SYSTEM
Supply chain system
FOB processes

LEAN THINKING
Waste reduction
Less dependence on supply chain

SUSTAINABLE FOB

Inputs/Outputs: Supply Chain

Processes: Sustainable FOB

On-site power generation
Waste-to-Energy
Solar
Wind
Diesel Generators
Fuel

Reduce Demand
Air Conditioning/Heating
Lighting
Passive Systems
Integrated Power Management
Building Envelope

Water Treatment
Waste Management

Water
Food
Design decisions

• Much emphasis on power generation elsewhere
  – Lots of technologies, a lot in experimental stage
  – Active element, may become additional target of insurgents

• Instead decided to focus on passive elements
  – Thermal efficiencies of accommodation structures
  – Reducing water waste through recycling and reuse
Exploring the performance of different accommodation arrangements

<table>
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<tr>
<th>Type of Structure</th>
<th>Environmental</th>
<th>Operations</th>
<th>Social</th>
<th>Economic</th>
<th>Results</th>
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<td>Size of Supply Chain</td>
<td>Ease of Re-use</td>
<td>Energy Efficient</td>
<td>Ease of Assembly</td>
<td>Modularity</td>
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<td>Tent Structure</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>3</td>
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<tr>
<td>Modular Structure</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Containerised Structure</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
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A LEGO-like standardised structure ($ST^2$)
**ST² properties**

- Each block accommodates 25 men
- Fully incorporated within a standard 20ft container
- Steel structure
  - (+) excellent sectional stiffness, smaller sections can be used to provide equal support
  - (-) More expensive
- Glass-fibre reinforced plastic (GFRP)/polyurethane foam panels (sides) and polypropylene honeycomb (floor)
- Perspex windows – 7% more efficient than glass (u value of 2.7)
- Height-adjustable footings
- Estimated assembly – 4 people, 4 hours (16 man-hrs), based on equivalent amount of live event stage gear set up
- Allows for pre-calculation of power requirements, depending on size of base
- Etc. etc. – please refer to paper or the full tech report
Waste water treatment

(a) View of the composting bin setup. The layers of human waste are covered with woodchip.

(b) Diagram of the water treatment system:
- Water flows from other sources through a pump to the first stage of filtration.
- The filtered water then goes through a bioreactor tank.
- Further treatment is done through reverse osmosis and chlorine dosing.
- Water consumption details:
  - Maintenance cost: £180 per month for filters, bacteria, and parts.
  - Running cost: 240kWh @ 50,000 gal/day, 1 kW = £1.23.
  - £0.007 per gallon to treat.

Soak away process:
- Layers of human waste are treated in composting bins.
- The liquid collects in a soak away area to account for the liquid coming from the Desert Rose.
- This setup is simple to build, use, and dismantle.
- Finally, urinals are based on the existing military design.
- The latrine facilities reduce water usage by 100%.
- Two types of latrine facilities are utilized: composting bins and changing stations.

Water treatment and sanitation: central to the whole process is the proprietary treatment system.

Environmental considerations:
- ISO containers are utilized for sustainability ratings.
- Materials are locally sourced as much as possible to reduce the supply chain burden.
- The standardised structure is 61.3% more efficient than traditional methods.

Security and observation: watchtowers called Sangars are constructed on the base for security and observation.

Water usage:
- Water consumption details are provided, including maintenance and running costs.

Sustainability:
- Sludge is removed and stored in a bin, which is collected and treated.
- The treatment process is very important to prevent waste from leaking into the soil.

Effective drainage:
- The framework is wrapped with PVC tarpaulin to prevent water loss.
- Effective drainage of maximum water into the shower trays is ensured.
- Chlorine dosing is used to ensure effective drainage.

Reverse osmosis:
- A reverse osmosis diffuse mechanism is used to achieve highly cleaned water.
- The process requires less energy than a normal filtration method.

Recycling:
- Water treatment and recycling are used for all applications.
- Recycling is used for larger areas such as the dining facilities.

Efficiency:
- The shower trays are lightweight form moulded GFRP, making the shower feel powerful.
- The water treatment process has a demand of 28% and water usage of 27%.

Construction:
- The construction process is quick-fit and modular, allowing for ease of assembly and disassembly.
- The showers are traditional designs, with a reverse osmosis diffuse mechanism for cleaning.

Sustainability ratings:
- The sustainability ratings of a FOB are expected to make a significant difference.
- Discussions on the importance of local sourcing and material use are provided.
Waste water system properties

• Composting looses produce rich soil compost
  – Can be used to re-fertilise land after use or in general to maintain the quality of the soil
• Fits into two 20ft ISO containers
• 20klt pillow tanks can be flat packed
• Peak flow rate 450lt/min
• If micro generation exists showers can plug into it for added boost
  – otherwise conventional black bag system can be used
• Aeration showerheads
  – reduce the amount of water required whilst maintaining good pressure
Lifecycle of our sustainable FOB concept

- The lifecycle of the sustainable FOB follows a sustainable process
- Robust and re-useable components can be removed from the site and re-used at another FOB or moved to storage
- Management of this lifecycle follows that of the ‘packaged’ FOB system
Design evaluation: Areas of impact

Perceived benefits from our design interventions identified within the FOB and its SoS context
Design evaluation: Simulation based on IES VE

Figure 6. Energy demand in a sustainable FOB

Figure 7. Heating and cooling demands of a standardised structure vs. a typical tent

Figure 30: Comparison of annual peak demand of sustainable FOB and the current FOB
OK, what’s the catch?

- Up-front capital expenditure is nearly doubled
- Annual operating cost nearly halved

Table 2. Aggregate figures of costs

<table>
<thead>
<tr>
<th>Key Financial Information</th>
<th>Current FOB</th>
<th>Proposed FOB</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Capital Cost</td>
<td>£520,600</td>
<td>£972,800</td>
<td>+87</td>
</tr>
<tr>
<td>Annual Operating Cost</td>
<td>£10,400,000</td>
<td>£4,800,000</td>
<td>-54</td>
</tr>
<tr>
<td>Annual Fuel Cost</td>
<td>£235,100</td>
<td>£131,200</td>
<td>-44</td>
</tr>
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</table>

- Not sure we can convince policy makers of the value – what do you think?
Thank you!

Any questions?

With many thanks to:

George Cave, Will Greenwood, Max Harrison and Amina Sadiq, now all MEngs in Civil Engineering