BEING BOLD

Facing our challenges

New Zealand IPWEA INSTITUTE OF PUBLIC WORKS ENGINEERING AUSTRALASIA

Sustainability: *"Life, Liberty and the Pursuit of Negative Entropy"*
Part 2: Transportation, Resiliency and Artificial Intelligence

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EDINBURGH LIKE DUNEDIN, BUT FURTHER

Learning Objectives

Objective 1 - Use the "entropy-based resource management" organizing principle to help your community achieve a sustainable economy and environment

Objective 2 - Develop holistic, multi-resource strategies for sustainability, resiliency (to climate change) and the advent of driverless cars and autonomous vehicles

Objective 3 - Assess how you might collaborate with other disciplines to integrate your current research into a comprehensive and effective sustainability strategy

Does your community need a…..

- Sustainable land use plan?
- Sustainable roadway grid?
- Strategy for climate change?
- Strategy for driverless cars?

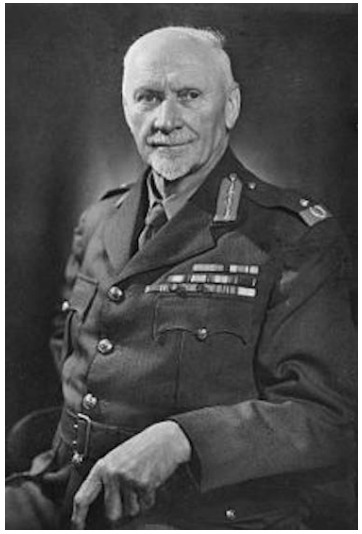
Are your.....

- Commutes miserable?
- Air quality alert days increasing?
- Wetlands drying up?
- Summer stream flows lower and more polluted?
- Wells drying up?

.....entropy-based resource management is for you!

Concept

Sustainability
"Mr. Malthus – meet Mr. Smuts"



http://centerforsi.org/index.php/2018/05/11/clark/

Entropy-based resource management

- Natural processes always minimize energy loss and leave all resources in a *state of minimum entropy* afterwards
- The resource is always maintained in its highest, most ordered state, at the highest energy level possible

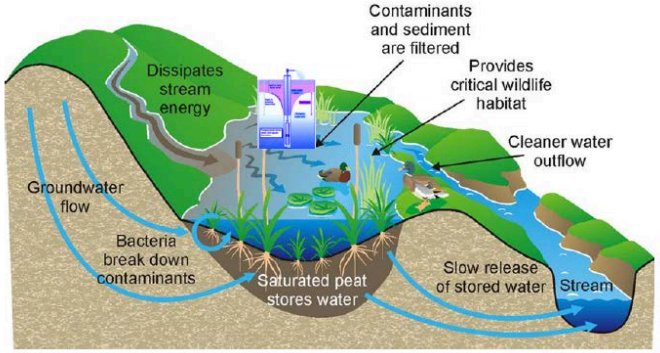
Try to create and maintain order, to *"create negative entropy"*, in all things, in all places, at all times

Natural Examples

1. Snowpack

Water in solid phase at the highest possible potential energy

….next best thing??



2. High groundwater

Water in liquid phase at the highest possible potential energy

"Pump up the groundwater (then plant everywhere)"

The entropy-based resource management "organizing principle"……

- Brings separate initiatives, covering multiple resources, together in a holistic sustainability strategy
- Establishes order, not only on the molecular scale, but also in all other management, planning and regulatory operations.

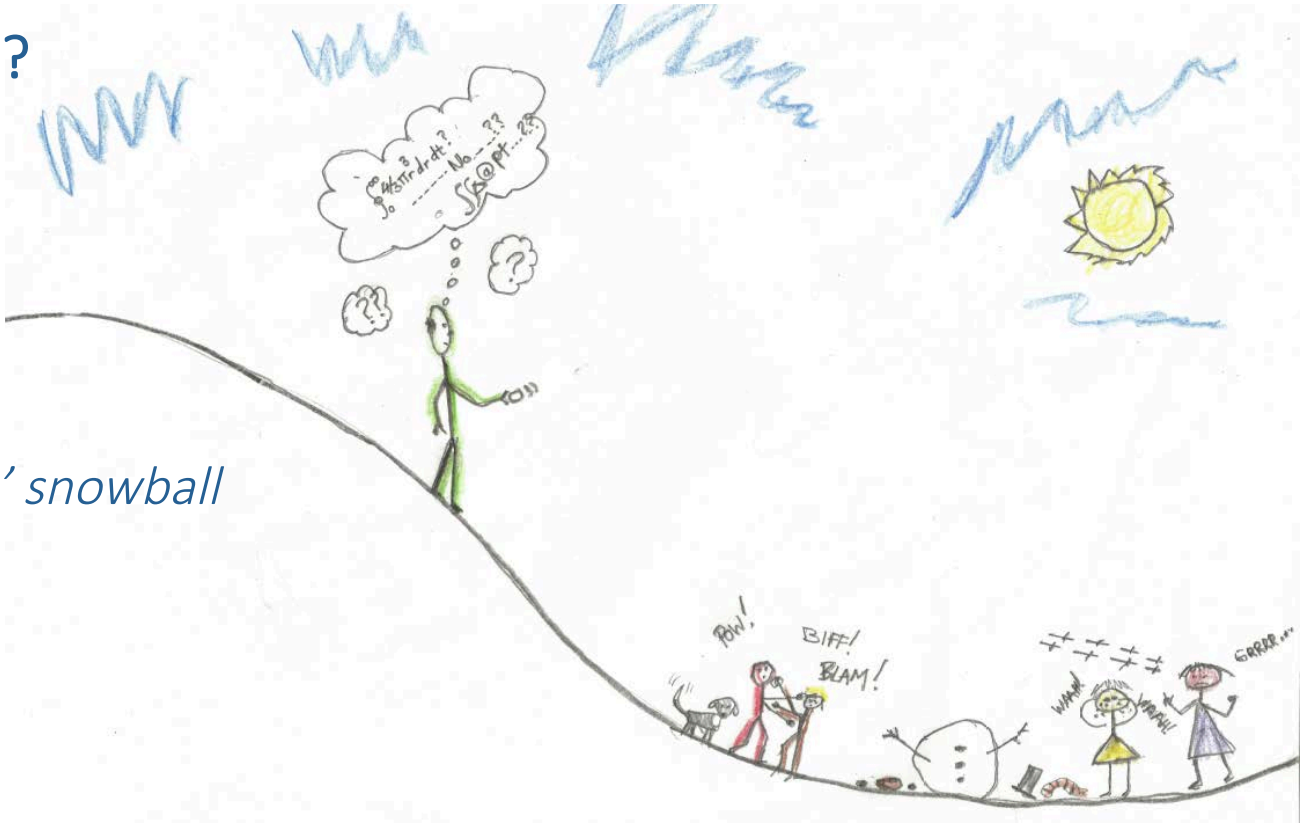
……and does it quickly and cost effectively

The effective storage and frugal use of our natural resources:

- Use those resources we need to live sparingly
- When you've got too much, store some for later when you'll need it more

Organizing principle??

"Just roll the bloomin' snowball down the hill!"



Part 2 Literature Review

Entropy-based transportation strategies

Transportation planning: *"A tale of two entropies"*

1. *Minimizing* entropy in traffic management: *Reducing energy use*

"About the analogy between optimal transport and minimal entropy";
(Gentil et al., 2016)

2. *Maximizing* entropy in traffic management; *Optimizing choice* in transportation options and routes

"Maximum Entropy and Utility in a Transportation System";
(Mazumber et al., 1999)

Other entropy-based traffic management techniques

3. “Entropy in urban systems”, (Cabral et al., 2013)
4. “Concept of transportation entropy and its application in traffic signal controls”; (Zhou et al., 2013)
5. “Cost-minimizing choice behaviour in transportation planning”; (S.B. Erlander, 2010)
6. “Entropy-based transportation model; a geometric programming approach”; (Samata et al., 2003)

Here… have at it!

Using (27) in (18) the solution is

$$x_{ij} = \frac{\tau_{ij} D_j}{\sum_i \tau_{ij}} \quad \forall\, i,j$$

Exactly in the similar manner with the pair of Problem-VII and Problem-X if the inequalities (10), (11) in Problem-II hold with equality the relationships (24)-(26) reduce to (20),(21) the conditions for problem-I. If all inequalities are strict then we have

$$v_i = 1 \qquad \forall i$$
$$u_j = 1 \qquad \forall j$$
$$w = \left[\sum_{i,j} \tau_{ij} \right]^{-1}$$

So that the solution is

$$x_{ij} = \frac{\tau_{ij} x}{\sum_{i,j} \tau_{ij}}$$

To determine the solutions for the entropy models in general we must concentrated to algorithm which is easier to work with the u_j's and v_i's rather than the X_{ij}'s and to use equations (18),(19) to determine X_{ij}'s from the knowledge of u_j's and v_i's. The primal problem has only one constraint and through duality its Lagrange multiplier is found. Thus the primal problem is equivalent to an unconstrained optimization problem.

Algorithm I: To solve Problem-I we may use the following algorithm

Step-1: Set n = 0 and $u_j^n = \frac{D_j}{x}$

Step-2: Set n to n+1 and $v_i^n = \frac{O_i}{x\left(\sum_j \tau_{ij} u_j^{n-1}\right)}$

Step-3: $u_j^n = \frac{D_j}{x\left(\sum_i \tau_{ij} v_i^n\right)}$

Step-4: Test of feasibility- $x v_i^n \sum_j \tau_{ij} u_j^n = O_i + e_i^n \quad \forall i$

where e_i^n is the error in the ith constraint. If $|\, e_i^n \,|$ is less then a predetermined tolerance for all i, then go to step-5 otherwise go to step-6.

Step-5: Test of optimality: $d^n = \sum_i e_i^n \log v_i^n$

where d is the difference between the logarithms of the objective functions for Problem-IX and Problem-VI. If $|\, d^n \,|$ is less than a predetermined tolerance, stop. Otherwise go to step-6.

Step-6: Set n to n+1 and $u_j^n = \frac{u_j^{n-1}}{\sum_i u_j^{n-1}}$ and repeat step-2.

Problem-III takes the form:

Problem-VIII:

$$\text{Maximize} \left(\frac{1}{e_0}\right)^{e_0} \prod_{i,j} \left(\frac{\tau_{ij}}{X_{ij}}\right)^{X_{ij}} (X)^X$$

$$\text{subject to} \sum_j X_{ij} - O_i e_0 + \rho_i = 0 \quad \forall\, i,$$

$$\sum_i X_{ij} - D_j e_0 = 0 \quad \forall j,$$

$$e_0 = 1$$

$$X_{ij} \geq 0\,,\ \rho_i \geq 0 \quad \forall i,j.$$

Now we are in a position to determine the geometric programming dual to the entropy models. In fact the dual of Problem-VI is:

Problem-IX:

$$\text{Minimize} \prod_i v_i^{-O_i} \prod_j u_j^{-D_j}$$

$$\text{subject to} \sum_i \sum_j \tau_{ij} v_i u_j \leq 1 \qquad (15)$$

$$v_i > 0 \quad \forall i$$

$$u_j > 0 \quad \forall j$$

The dual of Problem-VII is:

Problem-X:

$$\text{Minimize} \prod_i v_i^{-O_i} \prod_j u_j^{-D_j} w^{-x}$$

$$\text{subject to} \sum_i \sum_j \tau_{ij} v_i u_j w \leq 1 \qquad (16)$$

$$1 \geq v_i > 0 \quad \forall\, i$$

$$1 \geq u_j > 0 \quad \forall\, j$$

The dual of Problem-VIII is:

Problem-XI:

$$\text{Minimize} \prod_i v_i^{-O_i} \prod_j u_j^{-D_j}$$

$$\text{subject to} \sum_i \sum_j \tau_{ij} v_i u_j \leq 1 \qquad (17)$$

$$1 \geq v_i > 0 \quad \forall\, i$$

$$u_j > 0 \quad \forall\, j$$

Entropy-based transportation strategies

Application to other current issues

Transportation planning and land use

"Maximum Entropy and Utility in a Transportation System"; (Mazumber et al., 1999)

"Both entropy and utility can be adopted by skilful proponents to explain almost any form of transportation problem".*

*Utility = benefit from making economic choices such as home and workplace location. Important in land use planning.

Resilience to climate change

Sustainability and resiliency are essentially two sides of the same coin, having essentially the same solutions:

Electric vehicles:

- use less energy (sustainability)
- produce less greenhouse gases (resiliency)

Low Impact Development techniques:

- recharge groundwater supplies (sustainability)
- reduce flooding (resiliency)

Driverless cars and autonomous vehicles

- Entropy-based transportation strategies can establish energy-efficient *transportation networks,* for all types of vehicles

- *In the vehicle*, entropy-based (energy usage) algorithms can help optimize travel route choices

Smart Infrastructure and Artificial Intelligence

- Smart infrastructure can be the on-the-ground embodiment of well planned, entropy-based resource management systems
- Artificial Intelligence software can make the operation and maintenance of smart, entropy-based public infrastructure easier and more efficient

Entropy-based resource management

“Back-to-basics sustainability”

"The Sustainable City"
Entropy-based Resource Management Plan

Energy

Water

Air

Energy

Employ entropy-based transportation strategies to minimize the work needed for home-to-work travel and all other trips.

Develop energy-efficient electric vehicles to perform that work as efficiently as possible.

Supporting strategies:

- *Multi-modal transportation systems*
- *Replace fossil fuels with renewable* energy

Implementation measures:

- *Sustainable land use plan ("Smart Growth" plan)*
- *AI-enhanced "Smart City" infrastructure and operations*

Other compatible strategies:

- *Complete Streets, driverless cars, First Mile travel options, 20-minute Neighbourhoods, roundabouts, entropy-based limits on sprawl, etc.*
- *Solar energy, wind energy plus pumped storage, better batteries, artificial photosynthesis for fuel, etc.*

Water

Establish and maintain high groundwater elevations in all places at all times.

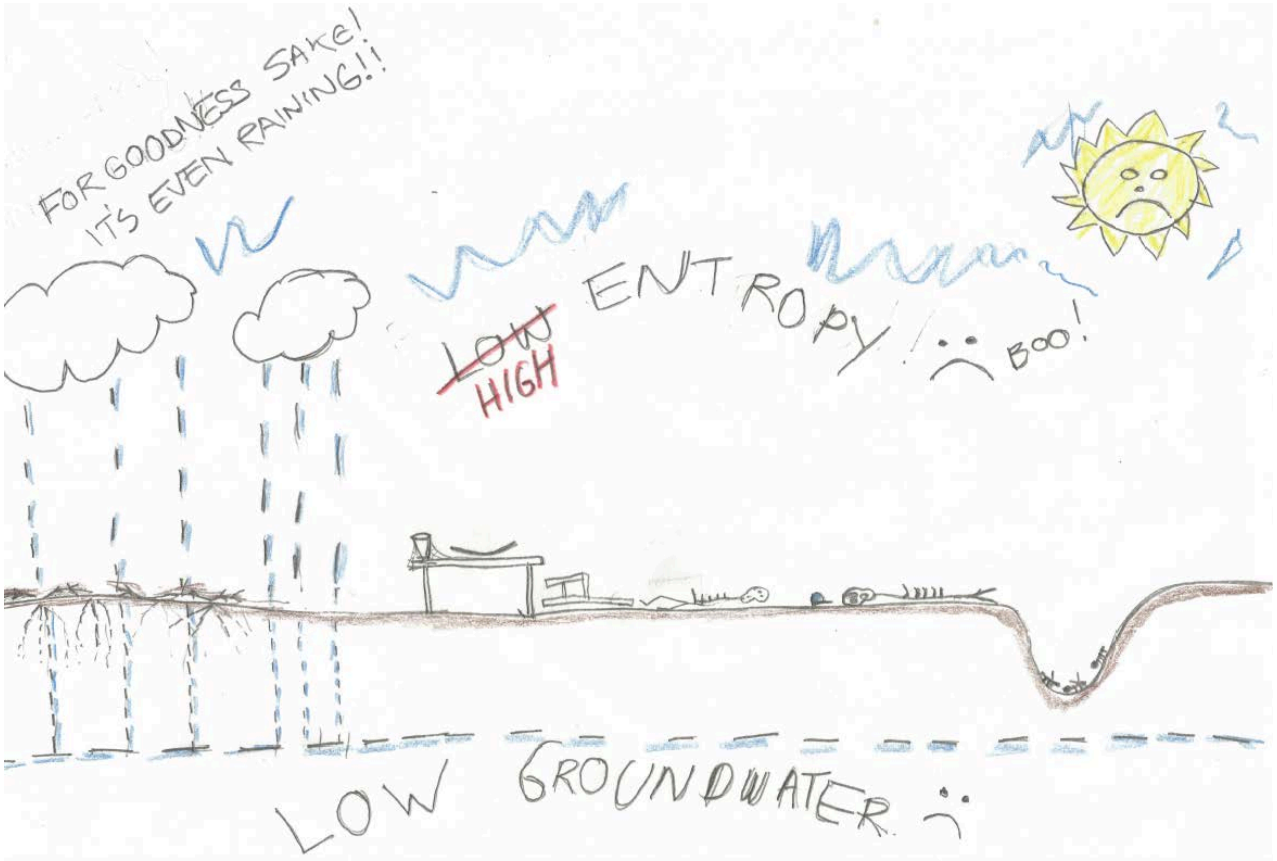
(Maximize retention of the annual rainfall supply/maximize the availability of water throughout the watershed)

Water:

Low entropy >
high groundwater ☺

Water:

High entropy >
low groundwater ☹



Supporting strategies:

- *Infiltration-retention-detention hierarchy for stormwater*
- *Flood flow capture and aquifer replenishment*
- *Headwater wetland restoration projects*
- *Trench dams in pipeline and utility trenches*
- *Runoff flow control*

Implementing measures:

- *Sustainable land use plan (incorporating "envirometric overlay")*
- *"Pump up the groundwater then plant everywhere"*

Other compatible strategies:

- *"One-Water" strategies, Low Impact Development BMPs, "Green Streets", "Smart City" infrastructure*

Air

Increase photosynthesis

Reduce greenhouse gas emissions

Supporting strategies:

- *Entropy-based watershed management strategies*
- *Entropy-based transportation strategies*

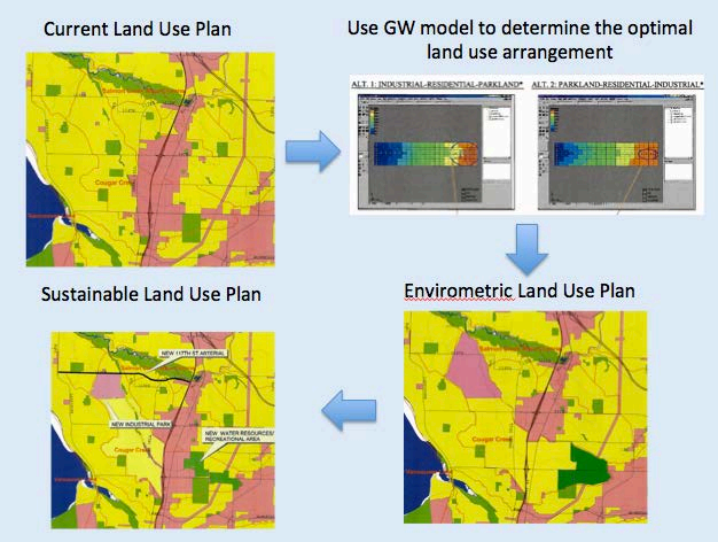
Implementing measures:

- *Sustainable land use plan (incorporating an "envirometric overlay")*
- *"Pump up the groundwater then plant everywhere"*

Other compatible strategies:

- *Electric vehicles, Reforestation*

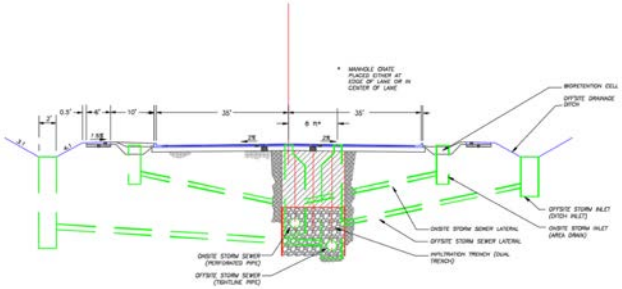
Smart "Smart Cities".....



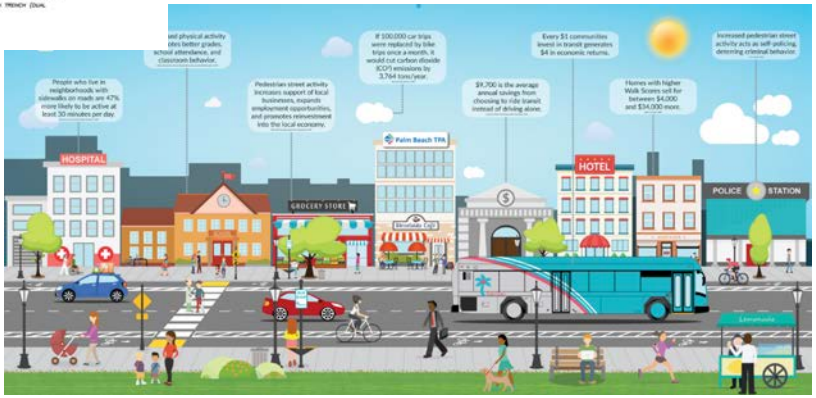
"Smart Growth" comprehensive plan

"Smart City" infrastructure

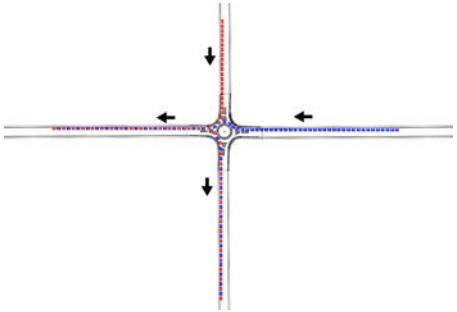
...with Green "Complete Streets"



Green Street



Complete Street...



(...including roundabout corridors)

Sustainability and Resiliency: *Are things bad enough yet?*

- In some places, maybe.
- In any case, there's no harm in being effective and cost-efficient, at any time...

Let's "walk-through" sustainability and resiliency, from an entropy-based resource management viewpoint...

Need: *Sustainability and Resiliency*

1. Lots for Public Works to do (without much money)...
2. We need to be very effective (and cost-efficient)...
3. A holistic strategy would consider all resources when making our management decisions...
4. Holistic, coordinated strategies can also achieve "whole is more than the sum of its parts" levels of effectiveness...

So, let's try to find a "holistic" strategy....

Purpose: entropy-based resource management; *a holistic strategy...*

5. A physical expression of "holism", and *a "holistic strategy"*....
6. Purpose is the frugal use and effective storage of all our natural resources *i.e. sustainability*....
7. The fundamental focus on entropy *opens up many physical, chemical and biological w*ays to achieve those goals....
8. The physical concepts are *well supported by mathematical analysis procedures targeted at systems-optimization,* our primary objective ....
9. Being based on natural systems, you can have confidence in achieving good outcomes, and so are free to have a *strong bias in favor of action*....
10. .... this, in turn, *allows fast responses to urgent resiliency needs*...

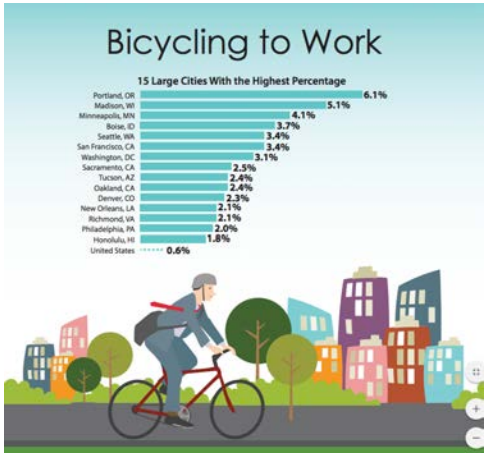
Entropy-based *transportation* strategies can...

11. Make very effective use of energy resources, and so are important when developing optimal transportation systems...
12. An optimized transportation system maximizes utility and so is an essential element of any sustainable land use plan...
13. Are good at (first maximizing then) optimizing choice in travel routes, and so can contribute to decision-making software for autonomous vehicles and driverless cars...
14. By reducing energy use, entropy-based transportation strategies also reduce emissions, a key resiliency need...

Smart City infrastructure and Artificial Intelligence software can then...

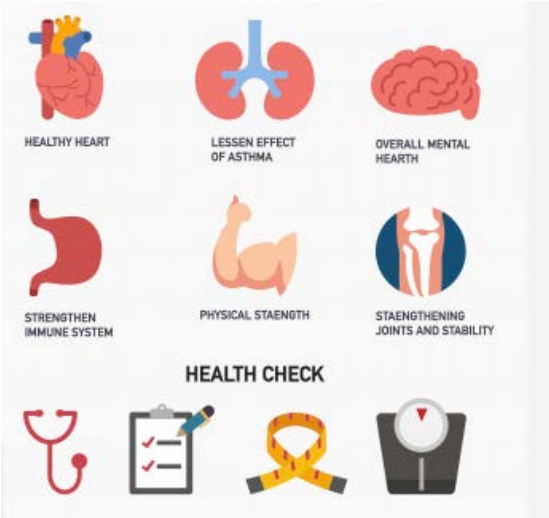
15. Operate and maintain that sustainable, resilient public transportation and infrastructure system even more cost-effectively...

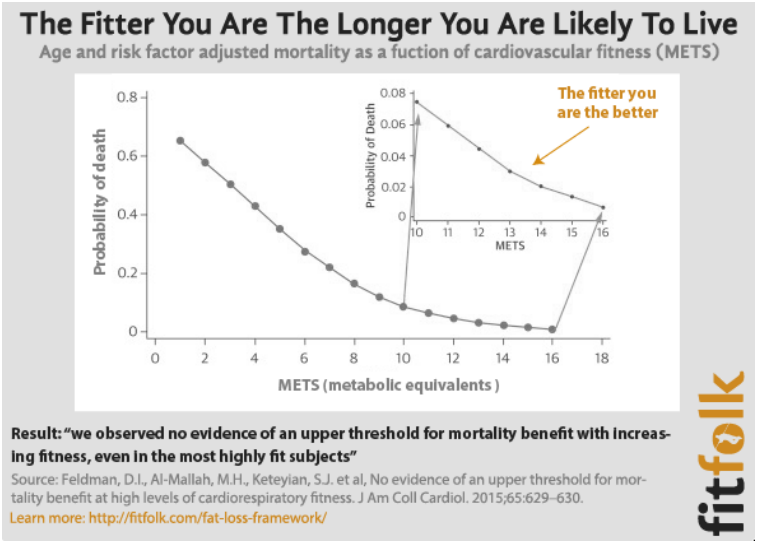
A holistic strategy: *design for Liberty…*



Multi-modal transport options – *use food energy first…*

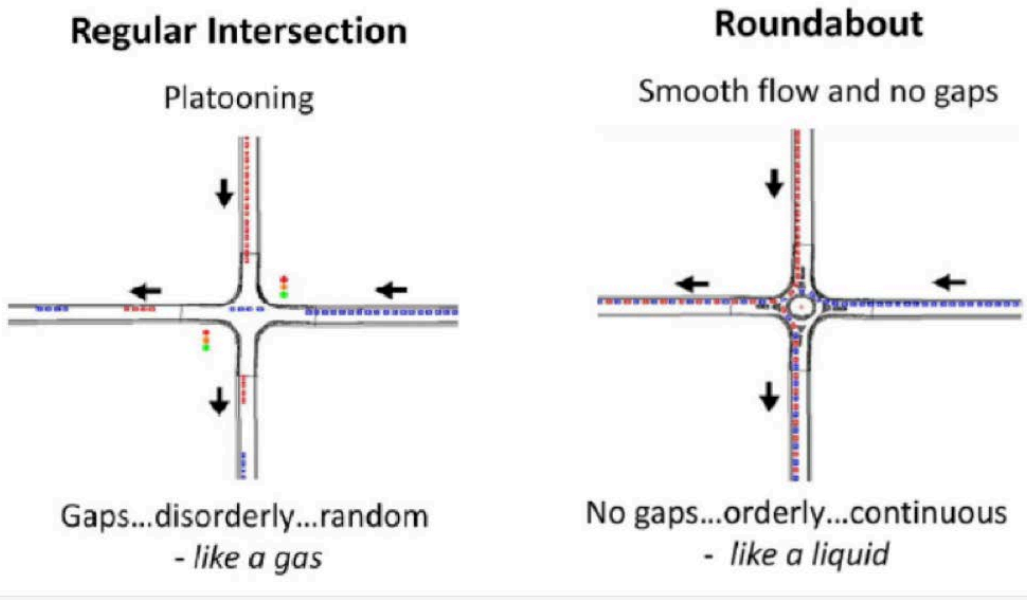
.... you get Life too!





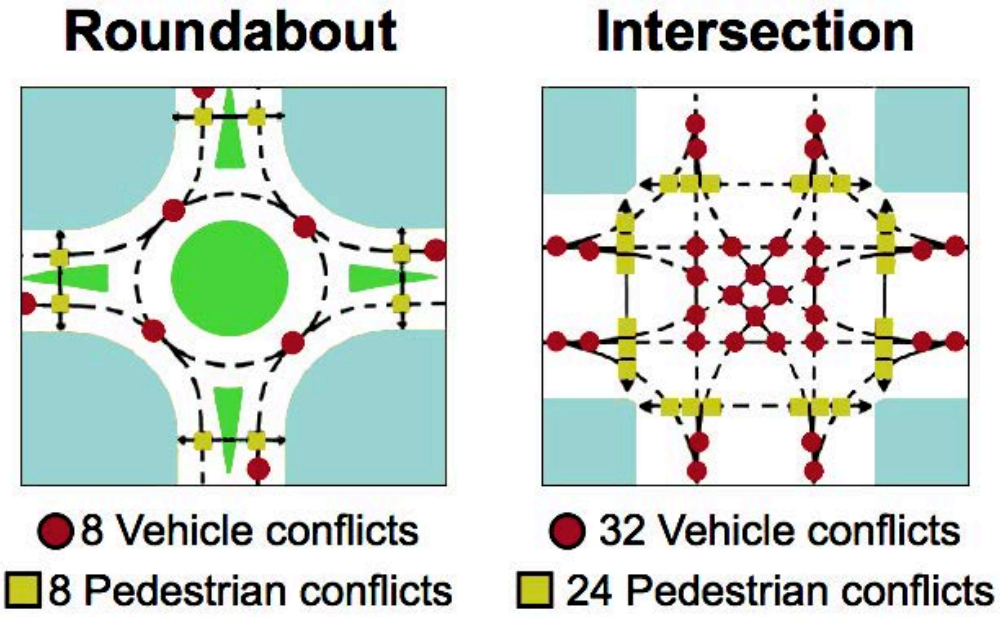
....folk are healthier and live longer

A holistic strategy: *design for Liberty…*



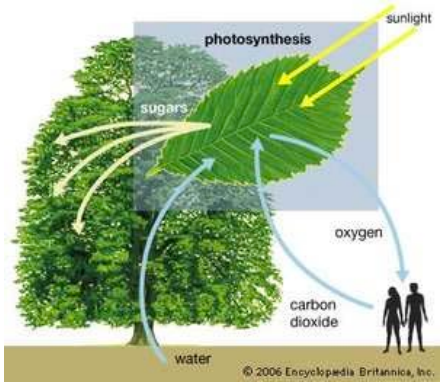
Add in *choice* – one more degree of freedom….

... you get Life too!



Sustainability for America!

"Life"



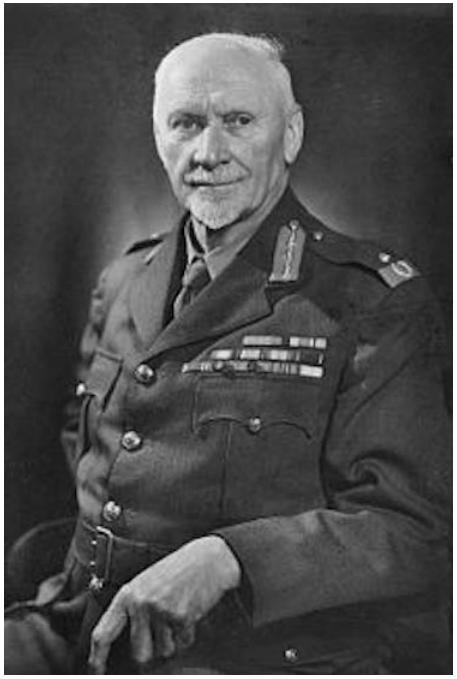
... and the pursuit of...

"Liberty"

"Negative Entropy"

Sustainability, mate???....

...a half-decent strategy and some good teamwork – that'll get the job done!



"When we try to pick out anything by itself, we find it hitched to everything else in the Universe"
- John Muir

"The ultimate purpose of life, mind, and human striving: to deploy energy and information to fight back the tide of entropy and carve out refuges of beneficial order"
- Steven Pinker

(For more information, go to:
https://www.clark.wa.gov/public-works/accreditation)