SUSTAINABILITY; “LIFE, LIBERTY AND THE PURSUIT OF NEGATIVE ENTROPY”

Part 2: Transportation, Resiliency and Artificial Intelligence

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Abstract

Clark County’s approach to stormwater management and watershed rehabilitation has focused on restoring the natural watershed hydrology using “entropy-based watershed management”. An earlier paper presented at the 2017 IPWEA conference in Perth, Australia, introduced this organizing principle, and extended its application to cover additional resources (energy, air) and additional disciplines (transportation, land use planning).

This concluding paper reviews additional research on entropy-based transportation strategies and reaffirms the value of using the organizing principle to develop comprehensive multi-resource sustainability strategies. The paper goes on to suggest how its use can also be effective in meeting newer challenges related to climate change and autonomous vehicles. The ultimate development of a sustainable land use plan, serviced by sustainable, resilient transportation and infrastructure systems that are further enhanced by Artificial Intelligence technology is envisioned.

Key Words: Sustainability, Resiliency, Climate Change, Artificial Intelligence.

INTRODUCTION

This paper describes how “entropy-based resource management” can be used to develop holistic, well-coordinated resource management and transportation strategies to help communities achieve a more sustainable economy and environment.

The paper builds upon an earlier work (“Part 1”) that introduced the entropy-based resource management organizing principle for the development of sustainability strategies. Although that paper focused mainly on water resources, it also included an example of using the organizing principle to develop a “sustainable roadway grid”, based on minimizing the entropy of traffic flow at an intersection. A sustainable roadway grid, as part of a sustainable transportation system, would be expected to contribute significantly to the development of a “sustainable land use plan”, another concept introduced in Part 1.

This follow-up paper (“Part 2”) completes a brief literature review of readily available entropy-based transportation analysis methods to explore the Part 1 suggestions in more detail. It then goes on to show how the organizing principle, as a holistic “back-to basics” approach to sustainability, can guide the development of a sustainable land use plan serviced by sustainable transportation and infrastructure systems. In so doing, the need for infrastructure that is both resilient to climate change and compatible with forthcoming Artificial Intelligence technologies can also be met.

THE ENTROPY-BASED RESOURCE MANAGEMENT ORGANIZING PRINCIPLE

Entropy-based resource management is an organizing principle for the development of strategies for the sustainable management of our natural resources and infrastructure. Its objective is to create and maintain order, i.e. to *create negative entropy*, in all our resources, in all places, at all times. The concept of creating and maintaining order is applied to all resource management activities, both physically (e.g. at the molecular level) and administratively, as in the development of a capital improvement program.

The organizing principle’s purpose is the efficient creation and storage, and frugal use of the resources we need to sustain ourselves. The focus on entropy offers us a wide array of physical, chemical and biological ways to achieve those goals. One relevant current objective here might be the pressing need to find effective energy storage mechanisms as we transition away from fossil fuels towards solar and wind power.

In Part 1, the organizing principle was applied to the field of water resources and watershed management, for the most part. Part 2 now explores how this organizing principle might be matched with other compatible research to develop sustainable transportation and land use planning strategies.

Before describing that match-up, an example of an entropy-based resource management strategy from Part 1 is reprised in this section.

Example; Sustainable Roadway Grid

In Part 1, the use of roundabout corridors as a default “sustainable roadway grid” was suggested.

The strategy was developed by noting that cars idling at a traffic signal intersection were causing an increase in entropy, a change in state from liquid (petrol) to gas, without performing any useful, productive work. If, instead, forward motion through the intersection could be maintained, that is if the intermittent “stop” condition could be changed to a “yield” option, then the total entropy change needed for a vehicle to travel that roadway corridor might potentially be reduced.

Put differently, a roundabout corridor, rather than a road corridor with stop signs and traffic signals, would require the least *energy* for a commuter to get from home to work, or for any other needed purpose and journey. By minimizing entropy (so minimizing energy use) we now have one element of a sustainable roadway grid.

The entropy-based resource management organizing principle, however, requires us to use a holistic approach that considers *all* resources and environmental attributes at the same time. Here, we can note that the least energy use will also result in the least emissions, lowest production of greenhouse gases, and cleanest air. Sustainability of both the energy and air resources, then, is achieved using a single transportation strategy.

Now continuing. The organizing principle, in its most basic form, requires that due consideration be given to *energy*, *air* and *water* at all times, the building blocks for maintaining life in the city. This can be achieved for the *water* resource by simply incorporating a green street roadway cross section within the roundabout corridor, to give us a truly holistic, sustainable roadway grid.

It is this type of simple but comprehensive and all-inclusive sustainability strategy that the entropy-based resource management organizing principle seeks to promote.

Moving from organizing principle to detailed strategies and procedures
The above example depicted the use of entropy based resource management to develop sustainability strategies. The organizing principle methodology is to use logical, qualitative and partly-quantitative thought processes to conceive and develop those strategies.

As entropy-based management methods move into implementation, however, the need for more detailed quantitative analysis arises. In Part 1, procedures such as the "maximum entropy method" (used in information theory) were suggested as promising ways to fine-tune a basic resource management strategy.

It is this refining stage of the resource management strategy, also completed using entropy-based analysis but now focused on transportation, which this Part 2 paper now moves on to consider. The first step, to complete a limited review of readily available entropy-based strategies used in transportation planning, is completed in the next section.

ENTROPY-BASED ANALYSES IN TRANSPORTATION PLANNING

A search of articles on entropy-based analysis of transportation and traffic systems immediately yields several lines of inquiry. Curiously, both the "maximum entropy" method alluded to in Part 1 and additional "minimum entropy" analyses (more like the entropy-based analysis used to develop the sustainable roadway grid) can be found. The reviews of the first two papers below bring out and explore this apparent contradiction.

<u>Maximizing</u> entropy in traffic management; Optimising choice in transportation options and routes.
The paper "Maximum Entropy and Utility in a Transportation System" (Mazumder et al., 1999) describes two techniques, a *maximum entropy method* and a maximum utility method, that can be used to optimize work trip-distribution in a transportation network.

The paper uses an entropy-based strategy and information theory mathematical techniques to develop a conceptual transportation network that optimises travel between the home and the place of work. The choice of the worker on where to live to optimize their commute time and general liveability (i.e. to maximize their *net utility*) is central to the analysis.

The authors end by stating that "both entropy and utility can be adopted by skilful proponents to explain almost any form of transportation problem". This confirms the value of entropy-based analysis in planning and designing transportation systems, and in developing land use plans.

<u>Minimizing</u> entropy in traffic management; Reducing energy use.
The article "About the analogy between optimal transport and minimal entropy", (Gentil et al., 2016) takes a similar approach to methods described in Part 1 to minimize the energy use (expressed as "entropic cost") within a transportation network.

Interestingly, the article uses mathematical representations of Brownian motion to find a solution to the problem. This is reminiscent of earlier analogous references to liquid and gas states that were used to determine the most ordered (least entropy) traffic flow through an intersection, which led to the sustainable roadway grid recommendation in Part 1.

Discussion

The previous two examples demonstrate the centrality of entropy-based analysis to the design of effective transportation systems. Seemingly contradictory approaches, a maximum entropy approach and a minimum entropy approach, were both found to be valuable in designing optimal transportation networks.

A closer look immediately resolves the apparent discrepancy. While the ultimate objective is to *minimize energy use*, this can also be indirectly accomplished by *maximizing the available travel choices* at the intersection. What remains curious however, is that entropy-based mathematical techniques were deemed the most effective way of solving both problems, as formulated, indicating that those techniques are likely to play a key role in any attempt at optimizing transportation systems.

In retrospect, this conclusion could perhaps have been apparent when developing the roundabout corridor example in Part 1. There, in order to *minimize* energy use, we essentially *maximized* choice at the intersection, by allowing the driver to make a stop-or-go decision themselves rather than have that decision determined for them electronically by a traffic signal.

The above two papers also show the physical (thermodynamic) concept of entropy and the statistical concept of entropy used in information theory to be entirely compatible.

Other entropy-based traffic management techniques

In addition to the two previous examples, the literature contains much additional research on the use of entropy-based methods in transportation systems analysis. Two additional papers are briefly discussed below.

“Entropy in urban systems” (Cabral et al., 2013)

This paper applies entropy theory to detect, control and limit urban sprawl, a land use condition that is considered to be “inefficient resource allocation”. The objective is “to find a land use plan that helps to achieve environmentally sustainable, socially acceptable, and economically viable urban development”. Minimizing social entropy in “transportation, utilities, services and in the arrangement of built-up areas”, can help achieve this.

A strategy that limits urban sprawl can clearly become a valuable contribution to the development of a sustainable land use plan, such as that envisioned in Part 1.

“Concept of transportation entropy and its application in traffic signal controls” (Zhou et al., 2013)

This paper introduces the concept of “transportation entropy” as a measure of disorder in a transportation system.

Transportation entropy is made analogous to thermodynamic entropy by regarding the vehicles as energy outputs. Common mathematical techniques can then be utilized to minimize the entropy, i.e. to decrease the disorder of the transportation system, when optimizing the traffic signal controls. A four-intersection network is then used to illustrate the solution.

The concept of order/disorder, depiction of vehicles as energy “packets” (my term), and the use of a four-intersection model all bear similarities to the sustainable roadway grid concept proposed in Part 1. That paper proposed the use of roundabout corridors as the most *orderly* traffic flow system, in a general sense.

Summary; Entropy-based analysis in transportation planning.

What is sure from a cursory review of the literature is that entropy-based analyses play a key role in the optimization of transportation systems. This outcome generally confirms the Part 1 suggestion to look to entropy-based mathematical analyses such as the Maximum Entropy Method when refining the largely qualitative entropy-based transportation strategies proposed in Part 1.

Some additional insights from the literature review are noted below:

1. The ubiquity of entropy-based methods used in traffic analysis points to the likelihood of using those methods, along with their supporting mathematical techniques, to develop algorithms needed for the introduction of autonomous vehicles and Artificial Intelligence technology into the transportation infrastructure.

2. Transportation planning is certainly concerned with the relationship between energy use and land use planning, and that inter-relationship is found to be well documented in the literature.

3. No linkages of entropy-based transportation strategies with air quality and climate change, as had been speculated in Part 1, were found in these particular references.

4. While entropy-based analysis is commonly used in transportation engineering, similar entropy-based analyses are not as evident in the water resources area. For example, regulations and other initiatives aimed at maintaining groundwater elevations, or increasing water retention and residence time within watersheds, have not yet been identified.

5. No examples of integrated transportation/water resources strategies were found.

Clearly, future link-ups can be made between the entropy-based transportation analyses methods listed here, air quality/climate change considerations, and entropy-based water resource management strategies. Based on the literature review, the need to develop holistic, multi-objective, entropy-based resource management strategies in the quest for sustainability, as suggested in Part 1, is confirmed.

The remainder of this paper will discuss these and more issues further, in reaffirming the entropy-based resource management organizing principle as a useful “back-to-basics” approach to sustainability.

ENTROPY-BASED RESOURCE MANAGEMENT: “BACK-TO-BASICS” SUSTAINABILITY

Implementation of entropy-based resource management, in the form of an organizing principle, is first of all intended to assure that all natural resources are considered simultaneously when developing new sustainability strategies.

The concept views sustainability as essentially a problem in applied physics, requiring a multi-resource approach by a diverse, multi-discipline team of experienced practitioners to solve. Nonetheless, it is an approach where the use of simple qualitative analyses can sometimes be sufficient to develop an effective new strategy.

This section discusses some aspects of using this holistic, “back-to-basics” approach to sustainability, using the material that was presented in Part 1 together with additional information uncovered during the Part 2 literature review.

Development of new multi-resource strategies

When a new multi-resource approach is first used, as opposed to an array of single-discipline analyses, it is logical that some simple new, holistic strategies may emerge. Combinations of practices that may potentially be very effective but have not been previously implemented would be discovered. For example the sustainable roadway grid described in Part 1 considered not only energy use but also air quality and water resources to come up with a new, simple but effective multi-resource sustainability strategy.

The organizing principle methodology first uses the simplest, most basic analysis methods to identify those new strategies. Those early analyses should be “as simple as possible, but no simpler”. We begin with purely qualitative assessments and only slowly, after the use of qualitative methods have been exhausted, do we move on to partly quantitative and, last of all, detailed quantitative analyses and modelling. (The "Hydrologic Accounting" procedure described in Part 1 is one example of a partly quantitative analysis).

While these analysis types might at first glance appear overly simplified, when compared with some of the sophisticated computer modelling that is ongoing today, they do impose new discipline and rigor by insisting that the full array of natural resources is considered at all times. Though simple, their value is confirmed if the resultant multi-resource strategy is found to be effective and there is no comparable strategy in current use.

Note that the refined entropy-based analyses identified earlier in the literature review were already fully developed. Part 2 merely suggests that they be combined with other entropy-based strategies to meet a wider range of sustainability needs. For example, any of the complex entropy-based transportation analyses reviewed earlier can easily be expanded into a sustainable roadway grid strategy simply by adding a green street roadway section. In this way the water resource would also be addressed (in addition to energy and air).

Combining complementary strategies

The literature review identified another approach that may have further utility as this organizing principle begins to be used more, that is combining two related entropy-based initiatives to form a more powerful and comprehensive strategy.

We begin with a second apparent contradiction. The optimal transportation network by Zhou et al. proposed using entropy-based traffic signal timing to develop the most energy-efficient and sustainable roadway network. While that proposal seems plausible, it appears to contradict Part 1's choice of roundabout intersections as the key component of an optimal roadway grid.

On closer inspection, however, it may be that the Zhou proposal was simply intended to apply to *non-roundabout intersections,* and so the two traffic management proposals may perhaps be complementary, not contradictory.

Continuing with this line of thinking, we can see that it may be possible to combine two or more existing entropy-based strategies to develop a joint strategy that may be more effective than any single-issue approach. Let's accept, for now, that a roundabout generally provides the most choice available to a driver approaching an intersection, and so generally promotes the most orderly, highest capacity traffic flow through that intersection. Let us accept also that a well-programmed signal may restrict a driver's choices only slightly more than a yield-based roundabout. These two findings, then, argue for a transportation network that includes a roundabout corridor as a first, default intersection option, then uses entropy-based signal timing at all other intersections in the roadway grid. We now have an example of combining two compatible entropy-based strategies to give us a more optimal resource management system.

Mimicking natural systems

Part 1 pointed to the value of mimicking natural systems when developing sustainability strategies. The papers reviewed here in Part 2 confirm the efficacy of that approach and expand its application, using more elegant and detailed analogues coupled with more rigorous mathematical techniques.

There may be many other situations where a full understanding and quantification of all the factors at play is difficult, even unachievable, but where simple, effective management practices can still be developed by mimicking the operations of a natural system.

As noted earlier, the article "About the analogy between optimal transport and minimal entropy" (Gentil et. al., 2016) depicted cars essentially as "energy packets", and then employed mathematical representations of Brownian motion to find a solution to the problem. A similar environmental mimicry approach was used in Part 1, where a simple qualitative assessment of liquid vs. gas characteristics was used to choose between a traffic signal and a roundabout as the default intersection for a sustainable roadway grid. Both mimicry approaches have merit when used appropriately in transportation network design.

Note that, while the mathematical techniques used in optimizing the traffic signal operation were complex, the simple, straightforward comparison of liquid vs. gas states put forward the roundabout, rather than the sophisticated entropy-based traffic signal operation, as the *default* intersection for a sustainable roadway grid. “As simple as possible, but no simpler”, if well formulated and well considered, can trump highly sophisticated analysis.

These examples point to the power and efficacy of mimicking natural systems to find simple new solutions to what might initially appear to be complex, intractable problems in sustainability.

Compatible regulatory practices

The value of using an entropy-based resource management organizing principle can also be seen by referring to two current regulatory practices. Both practices were developed independent of this organizing principle, but nonetheless apply its simple back-to basics approach to achieve very effective management outcomes:

- On the transportation side, while optimizing travel choice can be complex, the widespread promotion of multi-modal transportation systems, which adds choice in the *type* of energy to be used, can only produce good outcomes when included in a comprehensive transportation strategy.

- On the water resources side, the widespread use of Low Impact Development BMPs can provide great benefits for groundwater recharge (although groundwater *discharges* would also receive due consideration in a comprehensive entropy-based strategy).

So, “Complete Streets” and “Green Streets” are both good. However, the entropy-based sustainability candidate, a “Green Complete Street” (now addressing water, energy and air), may be still better. The sustainable roadway grid described in Part 1 can be thought of as an example of a Green Complete Street.

Resilience to climate change

While it is important that work on sustainability continues apace, attention more recently has shifted to the pressing need for resiliency measures to cope with climate change. In reality, sustainability and resiliency may be two sides of the same coin, and entropy-based resource management can help develop solutions that will work for both.

Although developed with sustainability in mind, the entropy-based resource management organizing principle can also be used in a more direct way to develop resiliency strategies. Entropy-based transportation policies and planning can develop road networks that lower the work requirements for home-workplace travel, while new hybrid and electric vehicles can travel those networks more efficiently. Both energy-focused sustainability strategies also help reduce greenhouse gases, satisfying a key resiliency need. On the water side, maintaining high groundwater elevations by capturing and infiltrating stormwater runoff, can offset a reduction in the annual rainfall supply, reducing the severity of droughts while also minimizing any increases in flooding brought on by climate change.

As problems of various kinds develop from climate change, the need for sound physics coupled with powerful mathematical techniques to find optimised solutions will grow. Based on the information covered in these two papers, the entropy-based resource management organizing principle can provide a useful and effective framework for developing those solutions.

Artificial Intelligence, Driverless Cars and Autonomous Vehicles

The introduction of driverless cars will create a still greater need for optimized traffic management systems. With human-made travel choices being supplanted by computer software, the need for sound, physically based algorithms that can fully optimize “electronic choice-making” will increase.

We've seen previously that entropy-based strategies are good at minimizing energy use and so can be valuable in designing efficient roadway networks for all vehicle types. We've also seen that entropy-based mathematical analyses can help optimize choice in making travel decisions, and so can also help with *in-vehicle* decision-making. This can be either by human drivers or by computer software incorporated into autonomous vehicles and driverless cars.

Based on the information found in the literature review, it appears likely that entropy-based traffic management strategies and their associated mathematical analysis techniques will play important roles in developing both the transportation systems and AI software that will be needed to successfully bring autonomous vehicles and driverless cars into the transportation system.

After effective transportation systems are established, AI-enhanced "smart infrastructure" can then help operate and maintain transportation and other public infrastructure systems effectively.

Of course, a rigorous, comprehensive application of the organizing principle would then require that all traffic systems employ the use of green streets in-between intersections, to give us a truly sustainable roadway network. Entropy-based strategies covering energy, air and water, the building blocks for life in the city, will now have been integrated and will work together to produce an outcome that is truly "more than the sum of its parts". We now will have a truly holistic and sustainable infrastructure system, cost-effectively serving a thriving city population.

"THE SUSTAINABLE CITY"

These two papers, taken together, have introduced and explored use of the entropy-based resource management organizing principle as a means of developing sustainability strategies, chiefly in the area of water resource management. This Part 2 paper has demonstrated that the organizing principle can be equally, if not more, effective in addressing transportation and related land use-planning needs.

Part 2 also showed that a well-thought out entropy-based sustainability approach can effectively address challenges arising from climate change. Entropy-based strategies and their supporting mathematical techniques can also help provide the algorithms needed for AI-enhanced infrastructure to further improve efficiencies within the transportation system, including the successful integration of autonomous vehicles and driverless cars.

All can be accomplished in a holistic manner, with each individual strategy supporting all others in a "virtuous cycle" or "positive feedback loop".

By way of illustration, an Entropy-based Resource Management Plan for a "Sustainable City", focused on the water, energy and air resources needed for life in that city, might include the following:

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

Develop energy-efficient, non-polluting vehicles to perform that work as efficiently as possible.

Supporting strategies are:

- Multi-modal transportation systems.
- Replace fossil-fuel energy with more easily available and efficient (and less harmful) renewable energy sources.

Implementation measures can include a sustainable land use plan that merges econometric analyses with entropy-based transportation systems. Ongoing operations would rely heavily on the use of AI and "Smart City" technology.

Other compatible measures include Complete Streets, autonomous vehicles and driverless cars, "First Mile" transportation choices, "20-Minute Neighbourhoods", roundabouts, entropy-based traffic signal optimization, vehicle-activated traffic signals, entropy-based limits on urban sprawl.

Supporting private initiatives include the increased use of solar energy, wind energy linked to pumped storage or underground injection of compressed air, turbines inside gravity water supply lines, electric vehicles, improved batteries, artificial photosynthesis for fuel.

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

This will maximize retention of the annual rainfall supply within the watershed. That in turn will maximize the residence time and general availability of water throughout the watershed.

Supporting strategies are:

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

Implementation can be achieved through the inclusion of an envirometric overlay within a sustainable land use planning process. In the absence of a detailed land use plan, “pump up the groundwater then plant everywhere” can serve as a reasonable envirometric *game plan* for a community faced with sustainability and resiliency challenges.

Other compatible measures include Low Impact Development BMPs, Green Streets, “One Water” strategies, Smart Infrastructure.

Air
Increase photosynthesis.
Reduce greenhouse gas emissions.

Supporting strategies are:

- Entropy-based water resource management strategies will increase the availability of water to encourage photosynthesis and vegetation growth, energy production and removal of carbon dioxide from the atmosphere.
- Entropy-based transportation strategies will reduce greenhouse gases and improve air quality.

Implementation can be achieved though use of a sustainable land use plan developed using econometric analyses integrated with entropy-based transportation and water resource management strategies.

Other compatible measures include reforestation, electric vehicles.

CONCLUSIONS

This Part 2 paper has completed a brief literature review of entropy-based traffic analysis methods to determine whether they can be linked-up with compatible entropy-based watershed management techniques to form holistic, multi-resource sustainability strategies.

The potential for developing integrated transportation and watershed management strategies was confirmed. Part 2 then went on to reaffirm the value of entropy-based resource management as an effective “back-to-basics” organizing principle for developing sustainability strategies.

The following general conclusions are also noted:

1. Entropy-based resource management strategies will also improve resiliency to climate change. Trusting that methods based on natural systems will always produce good results will also free us to include a strong bias in favour of action in our deliberations, allowing us to respond quickly to our most urgent resiliency needs.

2. Entropy-based transportation strategies can help effectuate the incorporation of autonomous vehicles, driverless cars and AI-enhanced "Smart City" infrastructure into our public transportation and infrastructure systems.

3. Entropy-based resource management can help conceive and develop physical, chemical and biological options for storing energy from wind and solar power-generation installations.

4. Multi-resource strategies and multi-discipline teamwork are both needed to produce the "whole is more than the sum of its parts" efficiencies of a truly holistic sustainability program.

Ensuring economic and environmental sustainability into the future can be achieved by a diverse, multi-discipline team using the entropy-based resource management organizing principle. With sustainability a continuing need, with resiliency to climate change becoming more urgent, and with the widespread incorporation of Artificial Intelligence technology into our transportation and infrastructure systems imminent, it's time to get started.

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