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Cross-Domain Comparison of Design Factors in System Design and Analysis of Space and Transportation Systems

Julia Nickel
Adam M. Ross
Donna H. Rhodes

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The tragedy of the commons

The tragedy of the commons

On the meadow…

… and in transportation

The tragedy of the commons

On the meadow…

… and in transportation

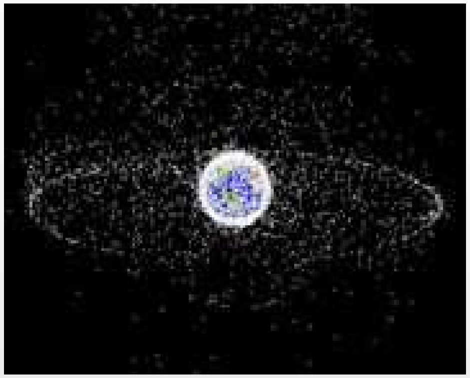
- Individual cost of adding a sheep (car, plane) less than the received benefit
- Public cost of an additional sheep higher than public benefit

→ **Congestion externalities**

Definition Externality: Causing of costs or benefits to third party stakeholders through a decision, often, although not necessarily, from the use of a public good

Space needs to deal with externalities too

Recent significant space debris producing events



- Chinese anti-satellite weapon (ASAT) test on January 11, 2007
- Russian Briz-M booster stage explodes in orbit over Australia, February 19, 2007
- U.S. launch of an SM-3 Missile from the USS Lake Erie. February 20th, 2008

(Wikipedia)

Solution approaches for externalities from transportation

- Congestion pricing
- Expansion of facilities (=public goods)
- Volume regulations
- Internalization of externalities (tax)

Rationale

Allocate cost to causer

Allocate goods to those that value them most

… Launch taxes?

… Laisser-faire?

…

Space can learn from transportation how externalities can possibly be dealt with.

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Need for domain comparitive research in systems engineering

- Knowledge of domain-inherent biases reduces likelihood of surprise by new problems arising from unexpected factors
- Cross-domain knowledge sharing in changing environment is enabled, new problems may be common in other domain
- Provides test cases for domain-independency of systems engineering theories

Motivation for the comparison of space and transportation

- Important commonalities suggest useful insights for both domains: high price tags, decade-long design phase and lifecycle, secondary objectives

  Examples for secondary objectives: Indian space policy: deterrence of China from future war with Pakistan through ballistic missiles; start of construction of $ 3.5mn airport in Akutan, Alaska

- Comparison of infrastructure* to less-infrastructure focused domain (More functionalities outsourced for transportation, resulting in heavier dependence)

- Development towards on-orbit infrastructure of space systems will likely start to exhibit characteristics and market failures as found in transportation (tragedy of the commons, externalities, free ridership, moral hazard problems)

* Definition infrastructure: Bundled system functionalities that do not create value but enable other missions, e.g. roads, rails, ports, launch infrastructure.

Space and transportation systems

Space systems define all of the devices and organizations that form a space network including spacecraft, mission payloads, ground stations, data links among spacecraft, mission or user terminals, launch systems; and directly related supporting infrastructure.

Example: Constellation of satellites

Transportation systems consist of physical objects, typically vehicles, the network infrastructure and equipment, and operation schedules that move passengers or goods.

Example: Bus network in a city

Agenda

Comparison in five subsections

1. Mission objectives
2. Stakeholders
3. System concepts
4. Constraints
5. Dynamic lifecycle issues

Focus of this talk: Comparison of domains as taught in typical graduate student handbooks.

Example books: Space Mission Analysis and Design, Wertz and Larson; Introduction to Transportation Systems, Joseph Sussman

1. Mission objectives

Definition of mission: Concise summary of the broad goals that the system should achieve

	Space	Transportation
Defined Mission Objective	• Integral part of design process • Single institution (NASA, DoD, military) in charge of capturing user needs and formulating mission	•Understanding varies • Not made explicit, inherent concepts • Multiple and conflicting goals (e.g. equity, (cost-) efficiency, sustainability) • Sensitive goals (pork politics)
Equity	Typically not considered	Essential to consider

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2. Stakeholders

Space

- 🟩 Federal government
- 🟦 Science community (both academia and government)
- 🟨 Military and intelligence communities
- 🟧 Aerospace industry
- 🟧 Sometimes commercial customers or international partners
- Others

Transportation

- 🟩 State governmental agencies, authorities
- 🟧 Private investors
- 🟧 Manufacturers and operators of vehicles
- 🟥 Adjacent communities
- 🟥 Customers
- 🟥 Broader society
- Others

🟩 Government

🟥 Personal, non-professional

🟦 Science

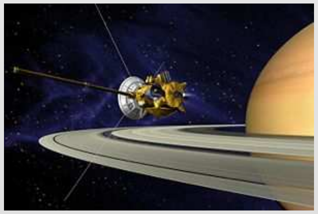
🟨 Military, intelligence

🟧 Industry, business

Broader system capabilities in transportation lead to larger market size

Non-professional and personal stakeholders add complications for transportation

2. Stakeholders

Stakeholder factors	Space	Transportation
Forced stakeholders	Not addressed	Addressed
Stakeholders with important informal power	Not addressed	Addressed
‘Losers’ (risk exceeds value)	Existing, but downplayed	Addressed
Example	Additional runway at Boston Logan Int. Airport (1975-2006) 	Cassini-Huygens probe (1997) 

Space design does only consider stakeholders that get value from the system.

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3. System Concepts

Concept factors	Space	Transportation
Understanding of concept	Mainly physical, payload determines value delivery.	Physical and operational. Quality of operation determines value delivery.
Inheritance	Not addressed. 'Soft inheritance' and launch infrastructure important	Hard and soft inheritance major issues

Example: Market for infrastructure
Expensive infrastructure sees a tradeoff between competition and maximization of use. Transportation systems evolved in several types, whereas there is only one market for launch choices (e.g. Delta and Atlas). Space can look at transportation for experiences with different systems.

Concept: mapping of function to form.

3. System concepts

Example: Unequal cost-benefit distribution of airport stakeholders

Local population, environment
Costs
-Potential re-allocation
- Noise
- Pollution
- Safety risks
-Extraction, drainages

Local economy
State/federal government
Airport operators
Private investors
Airlines
Benefits
- Economic boost through strong infrastructure

Concept factors	Space	Transportation
Compensation for losers	Not addressed, claims commission provided by 1972 Liability Convention never required	Common issue, addressed
Types of cost	Monetary	Multiple types of cost (monetary, environmental, social)

4. Exogenous factors

Constraints are unchangeable factors of any kind in the design process. They are individually derived from system exogneous factors.

Exogenous factors	Space	Transportation
Physical and technological constraints	Severe, especially orbital dynamics, required energy	Use of state of the art technology often not required
Maintenance	No operational capability, difficult due to remoteness	Important determinant for performance
Inherited infrastructure	Legacy civil and military systems	Major design factor, provides crucial functionalities
Dual use (military-civil), and other restricted technology	Yes, adds a lot of regulations, restrictions on technology transfer	Plays minor role, mainly civil use, national security an issue in border protection
Safety	Matters during launch and re-entry	Central emphasis on personal safety of passengers

4. Exogenous factors

Exogenous factors	Space	Transportation
Market structure	Small numbers of buyers and sellers	Monopolistic and oligopolistic structure, partially high competition
Social norms on performance	Survivability, robustness, reliability	Reliability, timeliness
Regulation	High	Regulations on international and all subsidiary levels, degree varying
Environmental constraints, land-use	Less important	Important
Impact of investment structure on design	Sunk costs of development, fixed launch costs	Discrete, bulky increase in capacity

5. Dynamic Lifecycle issues

Lifecycle factors	Space	Transportation
Definition of the end of a system's life	Typically operational end of life, or end of mission	Varying, disposal problematic, system exists while components are being replaced
Lifecycle	10-15 years	~10 (motor vehicles)-50 (airport) years, depending on utilization
Changing contexts	Important	Important

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Conclusion

- Space and transportation systems exhibit both common and domain-specific issues that need to be considered in research targeted at domain-independent theories and models (use cross-domain test cases).

- Knowledge-sharing across domains is highly desirable in issues of increasing importance for domains where they are not addressed yet.

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Thank you for your attention.

Questions?