Chapter 1
Perspectives on transport *of* water versus transport *over* water

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Abstract This chapter discusses the characteristics of transport *of* water, transport *over* water, and their relations. A framework is proposed aimed at integration of operational control and management approaches related to both fields. Providing this framework enables discussing how solutions presented in the literature related to either one, or both fields, could in the future be merged into a unified control methodology. This methodology will enable balancing the transport of and over water objectives, while respecting operational constraints. The main features of the unified framework are discussed and an overview of the main points that need to be addressed in order to relate ongoing research to this framework is provided. A brief summary of the main topics investigated, problems and methodologies proposed of a survey of 22 research directions related to this framework is subsequently presented, including references to further, more detailed information. As such, this chapter serves as the introduction to the book "Transport of Water versus Transport over Water: Exploring the dynamic interplay between transport and water".

1.1 Introduction

Transport systems have been around for centuries for bringing goods and people from one place to another. Whereas initially transport took place mostly over roads, soon alternative modes of transport started being used: transport over water, transport over rail, and transport through the air. Nowadays, transport using these different modalities is common practice. The trend is to move towards intermodal trans-

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port, in which commodity does not use one type of modality, but multiple types of modalities, chosen in such a way that costs, time of arrival and sustainability objectives are balanced.

Water is a particular kind of good, the availability of which is crucial for the survival of humanity. Mankind has long been developing transport systems to effectively move water from sources (springs) to places where it is consumed or disposed (as drinking water, for feeding cattle, for use in agriculture, for hygienic purposes, or for ensuring safety). Originally relying on the transport systems created by nature herself (rivers), at some point people started creating their own canal systems and storage locations for water. Transport of water systems were born.

The book *Transport of Water versus Transport over Water* explores the dynamic interaction between two vibrant areas of research: transport systems on the one hand and water systems on the other. Water systems and transport systems are two classes of systems that have received over the years a significant amount of attention. Initially, the research in these areas focused on how to design such water and transport systems. More recently, a strong research line is emerging with a focus on how to obtain the best performance for a given water or transport system, after it has been designed.

Of particular interest is the consideration of transport systems that transport water directly (such as river, canal, irrigation systems, among others) and systems that use water to transport goods (typically using vessels). Transport over water of goods, using a system for transport of water, poses challenging design and control problems. The objectives and relevant constraints for the different types of systems can be different. It is the question how these can be considered simultaneously.

For both water and transport systems, at an operational level, approaches have been proposed in the literature aimed at optimizing system performance at a day to day, hour to hour, or even minute to minute time scale. Nevertheless, approaches that consider the interaction between these two types of systems are lacking. However, at such fast time scales, to interplay between the two types of systems cannot be ignored. It thus becomes important to explore to what extent transport and water systems interact at an operational time scale, and how the dynamics of both systems can be aligned in the best way possible using operational control techniques. Many approaches are possible.

In short, design and control of systems for transport of water (e.g., river systems, open canal networks) have gained increasing attention due to changes in local land-use, climate changes, and the need for energy savings. In order to take into account a variety of different objectives, methods for control of systems for transport of water are being proposed. Besides the safety objective typically considered, navigation is another objective that is often relevant for such systems. At the same time and for the same reasons, design and control of systems for transport over water (e.g., navigation systems, vessels, barges) are gaining increasing attention. As the volume of goods to be transported in the near future is expected to continue to rise, and as transport over water is the most environmentally friendly mode of transport, the need for innovative transport over water systems is apparent. In order to obtain the best performance, such transport systems should take into account the particular

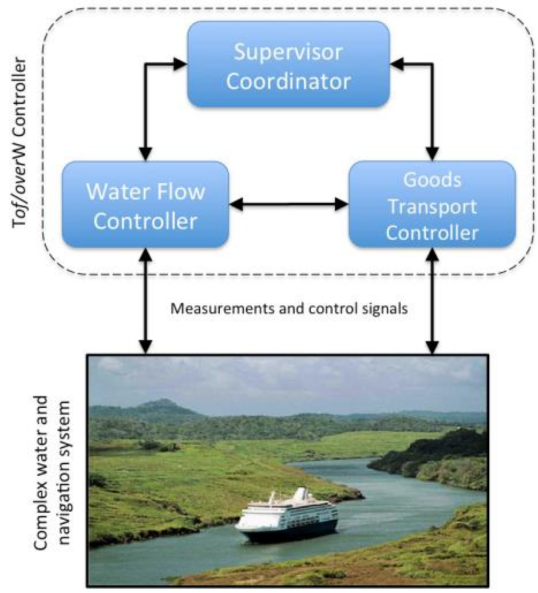

Fig. 1.1: Control framework and its interaction with the complex water system.

dynamics and behavior of the underlying water transport systems, which facilitate that transport over water.

The remainder of this chapter is structured as follows. In Section 1.2 we propose the unified framework merging transport of water and transport over water. In Section 1.3, the objectives of this framework are outlined while Section 1.4 shows what aspects need to be considered in order to achieve these objectives and detail the framework. Next, in Section 1.5, a categorization of a range of different problems treated by research community to transport of and transport over water is is provided, highlighting the most relevant methods to cope with them. Section 1.6 explains the way in which the approaches considered by the research community have been organized in the book Transport of Water versus Transport over Water. Finally, in Section 1.7 the main conclusions of the chapter are provided.

1.2 Unified interdisciplinary framework

The management of transport of water systems and transport over water systems involves important cross relations given by the interdependency of their dynamics when facing the fulfilment of overall control objectives. A simplified bottom-up framework that captures the main aspects for control of interacting water and transport systems can be seen as the composition of (see Figure 1.1):

1. The control of a first layer consisting of the water flowing through its infrastructure (without consideration for transport dynamics).
2. The control of a second layer consisting of a transport flow (without consideration for water dynamics).
3. The control of the interactions between both layers (water flow and transport flow).

On top of this, additional logistics-oriented layers can be considered, which determine from where to where transport flows are supposed to take place.

The considerations on the design of such a unifying framework is lacking in the literature. In fact, bridging the gap between both worlds could give rise to management policies that improve each system separately while optimizing further the performance of the overall complex and mixed infrastructure. The complexity in achieving the development of such a unifying framework lies in the truly interdisciplinary nature of the aspects needed to be considered. Expertise is amongst others required from the domains of mechanical engineering, civil engineering, hydrodynamics, automatic control, computer science, operations research, system identification, computer science, transport engineering, maritime systems, and ship design.

1.3 Overall objectives of the framework

This framework aims at stimulating discussion between researchers working on state of the art approaches for transport of water on the one hand and researchers working on state of the art approaches for transport over water on the other hand. As such, it aims at bringing together the different domains of expertise required to develop the unifying framework. Besides this, the main contribution of the framework as a whole is to present novel perspectives ultimately leading to the management of the envisioned unified management framework taking the recent advances form both worlds as a baseline. The framework:

- is devoted to become a reference for control-oriented engineers who manage water systems with either or both purposes in mind (transport of water, transport of goods over water);
- aims at promoting the topics of transport and water control;
- highlights the possible twofold nature of water projects, where water either acts as primary object of study or as a means.

1.4 Pieces of the framework puzzle

In order to achieve the objectives set out, a large number of research groups has been invited to prepare a chapter addressing in which way they work on transport of water, transport over water, and the interaction between these two domains. This has resulted in the chapters with a common structure, addressing the following aspects:

1. Introduction of the research in either transport of water, transport over water, or the combination, including exposition of relevant theoretical and application-based contributions.
2. Description and discussion of the specific case study or case studies, including overall description and presentation of main results and insights obtained.
3. Views on the nature of the unified framework, addressing questions such as:
   - How does the presented research take into account transport of water?
   - How does the presented research take into account transport over water?
   - What would be the benefit of the presented approach within a combined framework?
4. Proposal of working directions that deserve future research attention either on the presented and discussed approach or on the rising research coming from the unified network.
5. Concluding remarks regarding findings obtained so far.

When surveying the range of contributions presented in the literature, the different aspects of transport of and transport over water that have been considered so far and that need to be considered in the future become clear. This will aid researchers in their pursuit for developing methods that are better suited for providing an efficient operation of both types of systems.

1.5 Summarizing the outcomes

In total, we have surveyed 22 main research lines on transport of water, transport over water, and their interplay. The book Transport of Water versus Transport over Water contains the details of each of these research lines, presented by the key researchers developing those. Many of these lines address specific problem with a focus either more on the transport of water domain or more on the transport over water domain. Some of the lines focus more explicitly on a problem directly related to both domains. When surveying the research lines, it becomes clear that the following are the main problems being addressed:

- **Problems with a focus on transport of water**
  - Improving **water quality**; removing algae for efficient water transport; effectively transporting sediment through water transport systems [2]
  - Optimally handing **water quantity**; avoiding too much or too little water (avoiding floods and droughts); delivering water at the right time at the right place [16, 19]
- **Problems with a focus on transport over water**

  - Increasing safety of **navigation** in transport over water; improving ship manoeuvring; keeping ships efficiently at specific positions via dynamic positioning [5–7, 9]
  - Enhancing **sustainability**; decreasing energy consumption of transport over water systems; determining optimal power configuration for vessels [6, 12]
  - Improving the **logistics** of transport over water; estimating the travel times accurately; modeling the traffic in transport over water systems [3, 8, 12, 14]

- **Problems of a more generalized nature**
  - Addressing the tradeoffs at different **space scales**; modeling whole networks at macroscopic perspective; modeling transport of and over water at smaller microscale scales [2, 10, 14]
  - Taking into account explicitly **uncertainties**; modeling and preparing for variations in currents, winds, social influences, system understanding [1, 7, 10, 12, 18, 20, 21]
  - Benefitting from the interaction between **humans and automated systems** [10, 18]
  - Increasing the **cooperation** in transport of and over water systems; reactivating the transport over water market [12, 20, 22]

- **Problems focusing on the interaction**
  - **Balancing conflicting objectives** of optimal delivery of water versus optimal navigation over water [16]
  - **Designing** the interactions among ship-waterway physics, river-wetland connections, river-waterway-canal interaction [7, 8, 14]

The methods that are used to address these problems are a clear indication of the multidisciplinary nature of the domain considered:

- **Modeling (for control)**: Closed-loop identification, data assimilation, Kalman filters, probabilistic maps, potential fields, dynamical models, hydraulic models, LTV models [2, 9, 13, 15]
- **Different control techniques**:
  - **Centralized**: Uncertain control, delay-aware control, multi-objective control, nonlinear iterative control, predictive control, (automatically tuned) PI, nonlinear MPC, event-driven control, decentralized PI, optimization-based control, fault tolerant control [2, 4, 13, 16, 17, 21]
  - **Distributed**: single level, multi-level / hierarchical [11, 17, 18]
- **Operations research techniques** (planning): scheduling, routing, mixed-integer optimization [3, 21]
- **Integrated control and scheduling** [3, 20]
- **Economical analysis** [8, 22]
- **Proposal validation**: Virtually in simulation studies, physical lab experiments, gaming for education [7, 16, 22]

Details on all the above mentioned problems and methods, as well as their relation to the common framework of transport of water and transport over water are found in the provided references.

1.6 Outline of the book

The book Transport of Water versus Transport over Water categorizes the approaches investigated in the literature in two parts: the first part considers those chapters mainly focusing on the modeling, management and control of infrastructures related to the transport *of* water (water networks, rivers, irrigation canals). The second part collects contributions focusing on the transport of goods and/or navigation activities, i.e., systems related to the transport *over* water. Within both parts, research lines have been ordered in such a way that earlier chapters consider more integrated approaches among both fields of transport (*of* and *over*) while, as that integration decreases, chapters are becoming more related to either *of* or *over* fields. This organization allows the reader to identify and distinguish the proposed approaches and how the respective research lines treat and contribute to the unified framework discussed.

As mentioned before, each research lines offers its own discussion of the integrated framework in the light of the particular approach presented and discussed according to the field. Hence, many ideas arise for actually shaping the details of the proposed integrated framework naturally arise – the methodologies applied to one field (*of* or *over*) require new perspectives from the complementary field for the unified framework to be applicable. This leads to many interesting new research directions.

1.7 Concluding remarks

Methodologies and relevant approaches related to transport *of* water and transport *over* water have experienced a fast evolution over the past years via separated ways, although closely related by the common element of water. Moreover, case studies are everyday more challenging and complex, implying smart solutions to management problems mainly taking into account the possible interactions between systems and the consequent difficulties to cope with them.

The book Transport of Water versus Transport over Water provides contributions from recognized water-field researchers that also work in "real-world" applications related to diverse sectors of the water field. Research lines investigated are structured following a common format: starting with the problem formulation and description (according to the particular topic – of water, over water–), where the proposed approach is discussed and exemplified by means of a water case study. Next the explicit linking between transport *of* water and transport over water is presented and discussed for the particular proposed approach. Then, the open topics and directions of new/future research lines are proposed and, finally, the most relevant conclusions are drawn. The transport of/over water linking sections is what distinguishes this book: the link is shown, contextualized and highlighted.

The book will be useful for engineers facing complex applications and willing to use recent methods of identification and control in solving them. In addition, applied researchers looking for areas in which to contribute in reducing the theory/application gap and exploring practical issues. Both will take great benefit from the framework and approaches presented in this book.

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