Technical management of the cyber-physical waterway: it's all about managing complexity.

by

MSc. Eng. Michiel Coopman[1],

ABSTRACT

Organizations that manage inland waterway infrastructure (IWI), are rapidly introducing cyber-physical technologies or will do so in the next decade. They are evolving towards the cyber-physical waterway (CPW).

There is not one perfect way to manage the CPW but not all ways are equally effective. Managing a CPW, means managing complexity. Evolving to the CPW increases the overall system complexity rapidly. If not well managed, complex systems are vulnerable systems that are hard to maintain and expensive to modify.

Cyber-physical technology allows for remote-control of locks and bridges, predictive maintenance, optimal and automated adjustments of weirs, optimized traffic control etc.

These technologies are fundamentally different from classic waterway technology. We analyze these differences between classic waterway technology and cyber-physical technology on both a component and a system level.

We provide insight in the relation between technology characteristics and technical management. Understanding this relation is crucial to successfully implement cyber-physical technologies on the waterway. Based on this relation we explore the technical management and procurement strategy for the CPW.

We argue that technical management of the cyber-physical waterway reduces and manages complexity by aligning itself on system-boundaries and system-life-cycles.

We recommend organizing your technical management the way you want your overall CPW-technical system design to be.

1. Background

De Vlaamse Waterweg (Flemish Waterway) is a newly formed government agency in Belgium. It was formed at the beginning of 2018 out of merger of 2 existing agencies with different territories; *Waterwegen en Zeekanaal* in the West and centre of Flanders and *De Scheepvaart* in the East of Flanders.

De Vlaamse Waterweg NV now manages almost all inland waterways and infrastructure in Flanders, Belgium.

Over the last 2 to 3 decades, both Flemish agencies have invested heavily in cyber-physical technology for remote control and monitoring of Inland Waterway Infrastructure. In the time leading up to the merger, the different existing technical infrastructure was mapped, as well as the organizational structures and technical management, with the aim of integration.

The ambition of the newly formed De Vlaamse Waterweg, is to invest and utilize cyber-physical technologies on a large and organization-wide scale. A central question during the merger was, on how to do this in the most effective and efficient way. This paper builds on this analysis.

[1] De Vlaamse Waterweg NV (Hasselt, Belgium), coopmanmichiel@gmail.com

Although at first, technical analysis and organizational mapping were separate paths, it was soon found that both were in fact leading up to almost identical schematics. Borderlines between technical infrastructure and differences in implementations where near to identical to borders between organizational entities. The technical infrastructure had copied the shape of the organizational borders.

One might think this insight is trivial, little surprising and of little use. However, we will show that although this may be true for classic waterway infrastructure, it is of utmost importance to keep this in might when implementing cyber-physical technologies and re-designing your organisation. It can be used to your advantage.

We first describe the cyber-physical waterway. Next, we analyze the differences between classic waterway technology and the technology applied in the CPW on two levels: the component level and the system level. Based on this, we provide some guidelines on how to effectively and efficiently organize the technical management of the CPW.

2. The Cyber-Physical Waterway

2.1 General

In cyber-physical systems, physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities, and interacting with each other in a myriad of ways that change with context. (US National Science Foundation,2009).

Some interrelated and overlapping terms that are used around the world for cyber-physical technologies are smart-technologies or Industry 4.0 technology. It is the combination of IT-related and networked components into physical infrastructures such as locks, weirs, movable bridges and waterway-infrastructure in general.

2.2 Applications of the Cyber-Physical Waterway

The cyber-physical waterway (CPW) is a waterway where for example:

- ➔ Infrastructure is connected with different communication networks such as fiber-networks and wireless networks (GPRS, VHF, RF, …)
- ➔ level sensor data is combined with weather forecasts to predict water levels and to automatically adjust weirs in the whole area in the most optimized mode
- ➔ bridge, locks and weirs are remotely operated from one or more central control rooms
- ➔ traffic flows are optimized based on tracking and tracing of vessels and all other relevant information, estimated times of arrival are calculated and used for lock-management
- ➔ infrastructure is continually monitored to allow for predictive maintenance, such as, bridge-openings, brake-pad wear, vibrations, engine-temperatures
- ➔ safety is guaranteed by smart safety devices, such as ship-bridge collision detection systems and vehicle detection

3. Characteristics of the CPW on a component level

3.1 CPW components

Traditionally, IWI comprises of steel or concrete structures and electrical and electromechanical components. The components used to implement a CPW are IT-related such as embedded computers, software and network components. As such, they inherently have IT-related characteristics. As such, there is a difference in complexity.

3.2 Complexity of CPW components

One way of quantifying complexity is based on information theory. Based on Zander and Kogut (1995); with increasing complexity of knowledge, the speed at which this knowledge can be spread within the organisation diminishes. This speed relates with the speed at which the technology can be implemented. They distinguish several properties that determine this speed.

Based on these properties, we list the differences between traditional IWI-components and CPW-components.

Traditional IWI components	Cyber-Physical Waterway components
Slow technological development	Fast technological development
Long product life cycles (>10 years)	Short product life cycles (<10 years)
Compatibility forms not a big issue	Compatibility issues supplier depended
Knowledge largely supplier independent	Knowledge largely supplier depended
Knowledge relatively easily codifiable	Knowledge difficult to codify
Wide variety of possible contractors	Specialized contractors

Complexity is built in, in the use of CPW components. First because dynamics increases. Secondly because without proper standardisation, variety becomes very high aswell, even for components with almost identical function and purpose.

With cyber-physical components, component-life-cycles are much shorter. Time from design, to implementation, maintenance, modification and finally disposal can range between 2 to 20 years.

For example, a new concrete structure now and 10 years ago, will be more or less built and calculated in the same manner. It won't need much maintenance in the first 10 years and will last for 50 to 100 years. If you want to change it, you can use the expertise from a number of contractors which can provide the same composition of concrete. The technical drawings can be read and modified to the new situation by any qualified engineer.

When you install a Supervisory Control And Data Acquisition-software (SCADA), you'll need to choose from a large number of suppliers which each offer almost identical functions and feautures but require completely different knowledge and training to implement.

You will need the latest operating system and computer-hardware not older than 3 years. Immediately after installation, you'll need to install patches and updates and repeat this half-yearly.

You won't be able to connect to random brands of PLC, especially not when they are older than 10 to 15 years. During the product life-cycle of the SCADA system, hardware and operating system may change 3 times.

You may have the best documented project, if you want some extra functionalities, chances are you'll find nobody except the original programmer to help you.

Characteristics of the CPW on a system level

4.1 Component breakdown structure vs system-engineering

Traditionally, IWI is analyzed by decomposing the infrastructure in a physical bounded component-breakdown-structure; the waterway is composed of several locks and bridges, which in their turn are composed of several structural elements and a drive system, with an engine and brakes, with brake-pads which are mounted by nuts and bolts and so on.

In a CPW, several components are networked with components that are located outside the physical boundary of the object. Therefore, to analyze the CPW, a purely geograpical and physically bounded breakdown is impossible and a system perspective is more suited. This is the aproach found in the field of system-engineering. Each sub-system has a role to play and provides a service to the other sub-systems and combined they achieve a higher goal then just the services added.

You can distinguish functional systems such as a CCTV-system, an access-control-system, a dynamic traffic sign-system, an IP-based radio communication-system etc. but also underlaying and supporting systems such as the IP-network-infrastructure and components, operating systems, virtual servers, storage-facilities etc.

4.2 Complex (infra)systems

Another broadly accepted meausure of complexity, is the degree of interconnectivity. What is the effect of a change in one part of the overall system on other parts?

Traditional IWI isn’t much interconnected and the behavior on a system level is straightforward. Only a few important minimal specifications are needed to describe the waterway and its structures: maximum width and length of the vessels, underpass height and depth of the waterway. The design of the lock or bridge itself may vary almost freely. A failure of one component, usually has only a local effect.

The subsystems of the CPW have multiple interactions, they continuously exchange information and are interdepend. Give the fast technological evolutions and short life cycles, the sub-systems vary over time, as do the interactions. The effect of a change in one area often has an unpredicted effect on other systems.

To fulfil its purpose, for example remote control, the CPW needs to fulfil multiple functions (radio-communication, control, vision, etc.) with a diversity of systems that are not usually designed to be combined and interoperable.

These are the characteristics of a high complexity (Jacobs, M. A.,2013). The CPW is a complex infrasystem.

4. Technical Management of the CPW

A complex system that isn’t well designed and managed, becomes very vulnerable. A single failure or well-intended change can result in failure of the whole system.

The preferred way to manage complexity, is to reduce it. Reducing complexity can be done on a technical level and on an organizational level.

5.1 Managing complexity on a technical level

Reducing complexity on a technical level can be done by:

- Modular design
- Clearly identifying and defining interfaces between (sub)systems
- Using minimal specifications for the services and interfaces between (sub)systems
- Creating multipurpose, open in between-layers
- Utilizing open widely used technical standards
- Separating functions/services
- If unavoidable, proprietary brand-based standardization

To summarize, we need to design the system to allow for continuous, fast and easy updates, upgrades, adaptions, modifications, … in contrast with building something that will last unaltered for 100 years.

5.2 Managing complexity on an organizational level

Willem and Buelens (2009) argue that technical dependency runs parallel with knowledge dependency. The need to share knowledge between organizational entities is a function of the interdependency of these entities.

Otherwise stated: (Conway, 1968): "Any organization that designs a system will inevitably produce a design whose structure is a copy of the organization's communication structure."

A frequent form of technical management of IWI uses an organizational structure roughly based on two dimensions: by geographical location and by technological life-cycle phase, usually study, construction and maintenance.

This is rational for classic IWI. Coordination between geograpical location is easy, because of the very limited minimal waterway specifications. Coordination between life-cycle phases is relatively easy aswell, because of supplier independency, ease of codification, long life cycles etc.

Given the characteristics of the CPW-system and its components, this strategy becomes problematic.

To reduce and manage complexity for cyber-physical systems on an organizational level, organizational structure should be at least partially aligned with a divison into (technical) subsystems. This reduces the need to transfer knowledge and reduces variety. At the same time, this will automatically result in more transparant system borders, clearer system-interfaces and modularity.

To further reduce the need to transfer knowledge and to cope with the high dynamics it is favorable to manage the different life-cycle phases of the components of the same system from the same organizational entity.

These implications hold true, wether the organisation uses in-house staff or outsources most tasks. When using outsourcing, procurements for a subsystem should comprise and integrate the different life-cycle phases such as implementation, maintenance and renewal.

5. Conclusion

Technical management of waterway infrastructure used to be little dynamic and coördination was relatively easily done by dividing technical management into geographical bounded areas and using minimal technical specifications inbetween.

Inland waterways are now rapidly evolving towards complex systems. If not well managed, complex systems are vulnerable systems that are hard to maintain and expensive to modify.

Successful technical management of the CPW is done by reducing complexity and aligning technology and organizational strategy by adapting for specific technological and system characteristics. Use organizational entities that manage the whole life cycle of a subsystem accros a the geograpical borders.

In conclusion; design your technical management the way you want your overall CPW-system design to be.

References

1. Conway E. Melvin (1968) How Do Committees Invent, Datamation magazine, April 1968
2. Jacobs, M. A. (2013). Complexity: Toward an empirical measure. Technovation, 33(4-5)
3. US National Science Foundation (2009) Cyber-Physical Systems (CPS) nsf08611
4. Hermann, M., Pentek, T. & Otto, B. (2015). Design Principles for Industrie 4.0 Scenarios - A literature Review (Working paper). (01), 13.
5. Willem, A. & Buelens, M. (2009). Knowledge sharing in inter-unit cooperative episodes: The impact of organizational structure dimensions. International Journal of Information Management, 29(2), 151–160.
6. Zander, U. & Kogut, B. (1995). Knowledge and the Speed of the Transfer and Imitation of Organizational Capabilities - an Empirical-Test. Organization Science, 6(1), 76–92.