# SYSTEMS THINKING IN DESIGN EDUCATION – THE CASE STUDY OF MOBILITY AS A SERVICE

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## ABSTRACT
Designers are faced with more complex, environmental and societal challenges than ever before. Those challenges require the ability to see how things are interrelated in the bigger picture and to analyse multiple causes and effects, rather than working from a siloed point of view. Systems thinking is a strong tool to enable designers and engineers to understand how an entire system works and how elements in the system are interconnected.
This paper demonstrates an approach to systems thinking and an analytical tool that could be applied to teaching future designers and engineers. This approach was used in the final year Advanced Design Management module during the 2023/2024 academic year at Aston University. This paper introduces a real-world Mobility as a Service (MaaS) trial that is implemented in the UK as a case study. It involves highly complex socio-technical systems whose investigation requires systems thinking. Cognitive Work Analysis (CWA), a systems level approaches, has been applied as part of the User-Centred Ecological Interface Design (UCEID) process.
Guidance will be provided to facilitate students' learning of an analytical tool for comprehensive system analysis and modelling. The benefits of applying systems thinking in the design and development processes of products and services based on a holistic understanding of the systems in which they are incorporated will also be explained.
The knowledge generated in this work is expected to inform design educators to recognise the importance of systems thinking. Ultimately, this will help them consider and apply systems thinking successfully in their teaching of relevant subjects with the enhanced knowledge of a systems level approach. This will facilitate future designers' problem solving of complex issues.

*Keywords: Systems thinking, User-Centred Design, Mobility as a Service (MaaS)*

## 1 INTRODUCTION
Contemporary societies are facing increasingly complex challenges and often they could have a ripple effect globally. Such challenges are "engineering system problems" that require cross-disciplinary effort and input [1]. They are often viewed as wicked problems as it is almost impossible to identify a specific cause or solution because the system components are highly interconnected. Systems thinking enables the complexity to be more fully recognised and embraced when addressing such problems [2].
Modern engineered systems tend to be combinations of social and technical elements [3]. Those systems are created to serve the users, rather than the technology itself, the users being one of the most important factors that constitute the system [4, 5]. Therefore, this study focuses on an approach to investigating complex sociotechnical systems as part of user-centred design whose primary aim is to maximise usability of the designed elements. Despite the well-known benefits of systems thinking, it is challenging to teach systems thinking and how to apply it in students' learning activities due to increasing complexity inherent in systems.
This study demonstrates an approach to facilitate students' understanding about systems thinking and their competency to use suitable approaches to their own learning. A real-world example of Mobility as a Service (MaaS) has been used as a case study for which a trial is currently being conducted in the Solent region of the UK.
The results of the study can produce benefits in the following manner. Teaching the systematic approach and relevant analytical methods could boost students' competence and confidence in applying systems

thinking in their studies and solving of problems that are often required in the context of highly complex sociocultural demands [6].

# 2 LITERATURE REVIEW

## 2.1 Systems thinking

Systems thinking has recently gained a significant attention in education research. A greater emphasis has been placed on systems thinking since the publication of the Benchmarks for Scientific Literacy [7], [8]. Understandably, it has also been incorporated in many curriculums globally [8].

Systems thinking is the cognitive ability to perceive wholeness rather than parts and pieces and to recognise the interconnections between elements in the system. It is suggested as being the ability to see how and why the system is organised and for whom [9]. Similarly, it is defined as the ability to comprehend "how an entire system works, how an action, change, or malfunction in one part of the system affects the rest of the system". It involves "judgement and decision-making; system analysis; and systems evaluation as well as abstract reasoning about how the different elements of work process interact" [10, 8].

Teaching systems thinking is important because complex systems have ambiguous boundaries that need to be judged from an appropriate understanding about how systems interact with their surroundings. Furthermore, once learners have a sufficient understanding about systemness, they are more likely to experience a distinct change in their ways of thinking about the world as well as their lives [9].

Modern engineered systems such as smart cities, automated vehicles and emerging systems enabled by artificial intelligence involve highly complex interactions among social and technical factors [3]. Those socio-technical systems involve complex interactions between humans, machines and the environmental elements of the work system. All those aspects should be considered when designing such systems [11]. Amongst those requirements, users' needs should be prioritised in the design of the systems to ensure usability of the systems. It is because the ultimate purpose of those systems is to serve the user, not to use the technology itself [4, 5].

Relevant principles have been suggested with the purpose to help inform the development of socio-technical systems in which user-centred design is incorporated as a key part. The focus is on the understanding of users, their tasks, the environments and specification of the context in which the system will be utilised [11, 5].

## 2.2 User-Centred Design

User-centred design processes suggest all the stages involved in a design and development life cycle. Each stage requires a deep understanding of the user who will be utilising the product [12]. It analyses potential users' preferences and needs in the initial stage in order to maximise usability of the product or service. It involves users to specify problems, to identify potential solutions and to generate inputs to refine the design outcome through iterative processes [13, 14]. However, how user-centred design is accomplished is left fairly open [5].

User Centred Ecological Interface Design (UCEID) suggests a novel method combined between user-centred and systems level approaches. It enables comprehensive analysis of a complex system with a focus on users' needs, capabilities and limitations. One of the human factors' methods that, is incorporated in the UCEID process is Cognitive Work Analysis [15, 16].

## 2.3 Cognitive Work Analysis (CWA)

Cognitive work analysis (CWA) is a methodology for the analysis, design and assessment of complex socio-technical systems. It has been used for various purposes, such as designing interfaces, decision support systems and analysing training needs [17, 15, 18]. CWA consists of five phases of analysis, but Work Domain Analysis (WDA), the first phase has been most commonly used [17]. The results are presented in the form of an Abstraction Hierarchy (AH). It helps examine system constraints such as physical objects, their functions and values related to the overall purpose of the system [15]. AH consists of five levels of abstraction from the most abstract level, 1) 'functional purpose' to 2) 'values and priority measures', 3) 'purpose-related functions', 4) 'object-related processes', to the most concrete level, 5) 'physical objects'. Each level includes elements (nodes) correspond to the characteristics of the levels. Nodes at different levels are linked by means-end links that presents the relationships between them [15]. Nodes linked at the adjacent level immediately above explain why the functions are needed. Nodes connected at the adjacent level immediately below show how the functions can be accomplished [19].

# 3 CASE STUDY

## 3.1 Mobility as a Service (MaaS)

MaaS is a relatively new mobility solution that aims to provide seamless transport that incorporates a range of transport modes and associated services that aims to meet users' travel needs through a single digital interface [20]. Its core elements include real-time information for all modes available in the area, technological integration to plan, book and pay to suit mobility needs [21]. It encourages people to use more sustainable travel methods and reorganises transport to respond to sustainability challenges by offering alternative to private car usage [22]. More societal benefits are expected as a result of wider acceptance.

However, there are various challenges in designing MaaS in order to ensure the potential benefits are fully realised. Although there have been successful MaaS trials, it is not easy to define an optimal version of MaaS for a specific region. One of the main reasons is MaaS is significantly dependent upon the characteristics of the existing transport systems [23]. In addition, a high level of integration of those systems makes it even harder to determine the scope of design tasks and areas to focus on than when designing a single system. This indicates that the successful design and implementation of MaaS need holistic understandings of the current transport systems that could generate more practical design considerations. This can be achieved through a systems level approach, rather than investigations that concentrate on isolated elements of the systems or independent observations of social and technical systems [19].

## 3.2 Implementation of Cognitive Work Analysis (CWA) – Work Domain Analysis (WDA)

WDA was implemented to describe constraints in the MaaS system as part of the UCEID process. Relevant constraints were identified from a user's viewpoint and positioned at five different levels in AH. For example, the system boundaries were defined with respect to the system as experienced by users. For the development of the AH, information from various secondary and primary data were used. They were sourced from government literature [24], academic literature [25], design workshop studies [26, 27], participant observation studies and the Solent MaaS app usability testing studies [28] performed for the project.

Nodes at each level were identified based on prompts as follows in the order of top to bottom levels. They include: what are the fundamental goals of MaaS and why it exists (level 1); how well does the system perform to accomplish the fundamental goals (level 2); what are the effects of affordances and roles of physical objects in the system, and how do they have an impact on the user or how do they benefit them (level 3); what are roles and functions of physical objects in the system (level 4); what are any artificial, natural or physical components in the system that matter to the fundamental goals of MaaS (level 5). An excerpt from the full AH developed for the project is given in Figure 1.

Insights are generated based on the interpretation of the AH as follows. The fundamental goals of MaaS includes accessibility, sustainability, convenience and efficiency of transport (level 1). There are multiple ways to achieve those goals, such as maximising financial and physical inclusivity, maximising time efficiency of travel and increasing micromobility use as shown at level 2. However, due to space constraint, this analysis will only focus on increase of public transport (PT) use as it is one of the most sustainable methods of transport. PT use could be facilitated by all the nodes defined at level 3, that include optimization of PT journey planning, ticketing and booking as well as travel cost. It could also be encouraged by motivating people to help protect the environment and by recognizing the health benefits of using PT. Nodes at level 4 and 5 represent how those purpose related functions identified at level 3 could be attained. As shown in the AH, there are various physical objects that include payment systems, mapping systems, traffic statistics and user analytics that enable those functions described at the higher levels.

This analysis could be particularly useful for learners to understand the entire system that is under analysis and to see how system elements are interconnected. It could also help them understand what other elements that are linked directly or indirectly in the AH should be considered in their design in order to maximise the desired impact of the products or services they are designing.

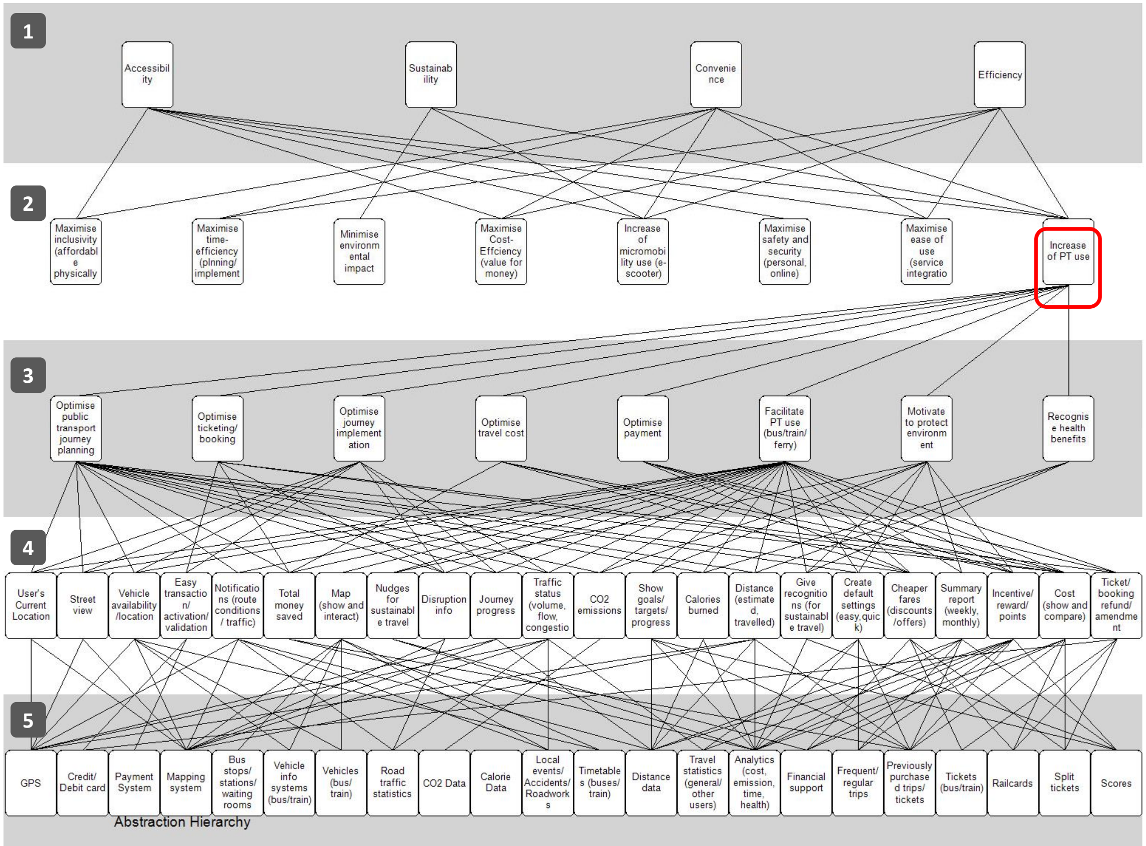


*Figure 1. Excerpt from Abstraction Hierarchy for MaaS for the Solent Mobility as a Service*

*Note*: Means-end links connecting nodes at level 2 and 3 have been removed excluding those connecting 'Increase of PT use' marked in the red box and those at level 3 due to space constraint.

## 4 DISCUSSIONS

This section provides practical guidance on how to implement the systems level approach in teaching that could support students' learning about systems thinking. It also discusses how the application of CWA techniques could facilitate students' ability to practice systems thinking in their activities. This method was applied in a small classroom environment for the final year Advanced Design Management module during the 2023/2024 academic year. The students provided highly positive feedback. They mentioned that the method helped them think about functions of the service elements being designed in relation to the wider system. They also said that using the techniques enabled them to organise their thoughts which can be beneficial to further develop their design ideas. They were surprised to see direct and indirect relationships between elements discovered in the AH which they had not recognised before. When applying the method, it is recommended to encourage students to apply a systems level approach in their own projects by adopting the following steps. They were modified based on the Revell et al.'s UCEID process [16]. These steps can be performed in one session or multiple session depending on how familiarized students are with their own topic. **First**, once students have an initial idea on what products or services they want to design (areas to focus), the context of design and aims of analysis need to be defined. **Second**, a literature review on the topic can be conducted, including industry reports, government reports, statistics and academic literature, depending on what is currently available in the domain. **Third**, data collection can be performed through various methods that include technology benchmarking, subject matter expert and user interviews as well as focus groups. **Fourth**, a systems-level approach can be implemented, such as CWA–AH based on the secondary and primary data. Explanations of the characteristics of each level in AH should be provided. It is recommended to encourage students to generate prompts for each level that suit the context of their own topic. It is because those prompts can inspire them to find relevant elements (such as physical elements, functions, values) appropriate for each level more effectively from the collected data. It is easy to start from the top level that explains the fundamental goals of the system, then to go to the bottom level that presents physical objects in the system. Once the bottom level is completed, roles and affordances of those physical objects can be identified and positioned at the adjacent level immediately above. Nodes at the middle level could be established considering the impact of those roles and affordances on the user. The second top level contains nodes that can explain how the ultimate goals of the system can be attained. **Fifth**, once, elements (nodes) are appropriately positioned at each level, means-end links need to be created between nodes at the adjacent level immediately above and below. It is important to guide students to think about the interrelations of the elements they pay attention to (such as the product being designed) with the elements that are directly or indirectly linked in the AH that can be done by reviewing the nodes connected by means-end links. For instance, this activity could assist students to consider alternative solutions, ripple effects or trade-offs between potential solutions. It is also advised to help students identify how functions of the products and services being designed could be achieved by reviewing nodes connected at the lower levels in the AH, and why those functions are needed to accomplish the fundamental purpose of the system by analysing nodes connected at higher levels in the AH.

These steps can be adopted in any stages of the design process, however it would be more beneficial to apply in initial stages of design processes, such as the concept development stage. Holistic understandings about the systems in which their product or services would operate will enable students to consider a variety of possibilities in subsequent stages. In line with the principles of user-centred design, this systematic approach can involve multiple iterations for optimisation of the design.

## 5 CONCLUSIONS

This study offers guidance in systems thinking and specific analytical techniques that could be applied in design related learning activities. Such techniques are a systems level approach within the broader context of user-centred design. A real-world case of MaaS was used as an example in which those techniques (CWA–WDA in UCEID) were applied. The processes could minimise ambiguity related to the identification of the system boundary and elements as well as their interconnections. Step-by-step instructions have been provided that could be applied in teaching systems thinking and practical skills. It is expected to facilitate students' understanding the functions of the product or service they are developing in relation to the entire systems.

Further work would involve teaching the approach detailed in this paper to an automotive specific module. For this, the Multiphysics System Design module on the Future Vehicle Technologies MSc at Aston University will be used during the 2024/2025 academic year. The teaching on the Multiphysics System Design module currently involves the development of control algorithms for autonomous vehicle operation, using the Roboworks Rosbot Plus TX robotic platform. Including the approach detailed above will give the students a chance to design the Roboworks Rosbot Plus TX robotic platform for a 'real life' operation/application.


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