Deriving Manageable Transdisciplinary Research Models for Complicated Problematics Associated with Next-Generation Cyber-Physical Systems:

Part 2 - Elaboration and Deployment

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Abstract: *This second Part of the paper (i) develops a detailed procedural model for handling complicated research problematics, (ii) transfers the procedural framework into a scenario of processing steps, (iii) demonstrates the deployment of the procedural scenario in a sample case, and (iv) addresses some important issues of research model development for supradisciplinary research. First, the framework called Holistic Systematic Combinatorial Scoping (HSCS) is introduced that comprises 21 subsequent activity steps. To illustrate the practical application of the HSCS framework, a demonstrative case study of preventing frequently occurring accidents at an uncontrolled intersection is presented. This case-study explains how the HSCS framework can facilitate (i) semantic capturing and rendering of complicated research problematics, (ii) scoping the overall research problematics and constructing definitive research problematics, and (iii) deriving a manageable research model of definitive research problematics. Further research intends to test the methodology by transdisciplinary research collectives and other CPSs related problematics.*

Keywords: Procedural framework, capturing problematics, constituents of problematics, dual-level reasoning, scoping problematics, definitive problematics, research model.

1 Introduction

As discussed in Part 1, problematics are complicated, heterogeneous, multi-faceted, and application-dependent research challenges (Pohl 2005), including technologically and/or socially-induced, large-scale research problems (Pohl and Hadorn 2008). To solve them, typically transdisciplinary knowledge input from multiple disciplines such as physics, biology, engineering, computing, social sciences, etc. is required, in addition to informing, training, and coordinating researchers (Hernandez-Aguilar 2018). Coordinating and integrating the knowledge and expertise from such different fields can be challenging due to differences in terminology, methodologies, and approaches (Garousi et al. 2016). Consideration of social/societal aspects as part of the investigated problematics increases the overall complexity, calls for holistic approaches, and needs collaborative efforts (Oosthuizen and Pretorius 2013). Bridging these gaps and fostering effective collaboration among experts are crucial, but still require effective communication and coordination (Sastrodiharjo and Khasanah 2023). The necessity for such a strategy was raised by the growing scales of research undertakings as well as by the emergence of large-scale societally-orientated problematics (Horváth 2023). However, the literature fails to offer effective strategies, especially in the case of handling supradisciplinary research (SDR) which combines interdisciplinary, multidisciplinary, transdisciplinary, and pluridisciplinary approaches from epistemological, methodological, and procedural perspectives (de Oliveira et al. 2019). SDR not only establishes research communities of enhanced social skills, but also operates with both a priori and posterior integration of knowledge of confounding disciplines, and complements the competences of researchers representing different disciplines to address large scale problematics on multiple levels (Mazzocchi 2019).

A fact is that mapping problematics for SDR is a challenging task not only due to their typically transdisciplinary nature, but also due to their wicked characteristic, dubbed as holism (Mokiy and Lukyanove 2022). A holistic investigation considers problematics as a compositional system. Compositionality is seen as one of the most crucial concepts not only in modern systems thinking, but arguably also in constructive research methodology (Li 2019). It is a system property predicated on the assumption that the properties of components remain unchanged through interactions with other components (Kopetz 1998). Eventually, it boils down to both epistemological and social issues. On the epistemological side, research collectives of investigators involved in SDR should strive for achieving compositionality in knowledge by synergistically integrating knowledge of the involved disciplines and to derive a holistic view based on this (Werning et al. 2012). On the social side, they should strive for learning the working and thinking cultures of the other parties, integrating diverse perspectives, and establishing effective communication channels by moving towards coadunation in their research projects (Sharia and Sitchinava 2023).

Due to the recognized ontological and epistemological similarities between research phenomena and research problematics, our hypothesis has been that the systematic combinatorial breakdown (SCB) method presented in (Horváth 2017) could be a proper starting point towards a holistic investigation and purpose-driven delineation of complicated problematics. In real life, comprehension of the existence of a research problematics may be the result of dedicated scientific exploration, rational analysis, or intuitive conceptualization. In any of these cases, the stimulation for further investigations may originate in the insufficient description, explanation, prediction, or regulation of some identified problematics (Horváth 2008). The SCB-method offers concepts and operations for further elaboration, manageable scoping, content demarcation, and formal representation of these towards sufficiently detailed but rationally investigable research models (RMs). Despite its affordances and utility, the SCB-method needs to be adapted according to the principles of holistic constructivism for complicated problematics, since originally it was developed for scoping complicated phenomena by the application of analytical reductionism. This adaptation is presented in the upcoming sections of this part of the paper.

2 Procedural Framework of Holistic Systematic Combinatorial Scoping

Following the reductionist reasoning, the SCB-method supposes that a phenomenon happens in a local world, in which it is modelled in terms of four foundational constituents, namely: (i) involved physical or imaginary things, (ii) their major distinguishing attributes, (iii) their contextualized functional relations, and (iv) their behavioral implications (Horváth 2017). Things are entities that can be observed or conceptually defined. Attributes are key characteristics or features of the things. Relations are associations between attributed things which enable regular or irregular behavior. Implications, also called effects, are outcomes of the relations and behaviors of the things under specified circumstances (Seikel et al. 2020). The SCB-method assumes that a composite phenomenon is a (non-compositional) union of multiple simple phenomena and interprets the complexity of a composite phenomenon as concurrent high cardinalities of simple phenomena, things, attributes, relations, and implications. The complication of the analysis and the decomposition sub-process originates in their intuitive nature and the large number of the possible combinatorial cases.

While reductionism has its merits, it can lead to oversimplification of complex problems (Havlík 2022). SDR requires transdisciplinary approaches for investigation. The first ingredient of its working strategy is integrating knowledge from multiple disciplines in a coherent and synergistic way. The second one is imposing the view of holistic constructivism on problematics. The third one is viewing problematics not only from viewpoints of the sciences, but also from the point of view of utility of the knowledge in practical applications. The fourth one is considering constructive research equivalent to explorative research in view of resolving complex problematics and finding solutions for the involved problems (Horváth et al. 2023). In SDR, imposing a holistic view on overall problematics facilitates the integration of diverse disciplines, addresses complex problems, uncovers emergent properties, transcends reductionism, and ensures practical relevance. It also aids researchers to navigate the complexities of SDR and contribute to a more comprehensive understanding and resolution of the problem at hand (Yeh 2019).

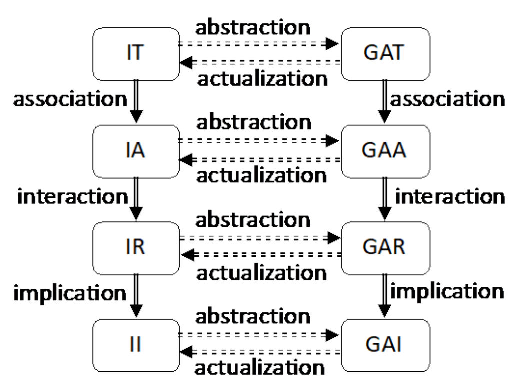

Figure 1: Semantic relations between instance and general/abstract constituents of a problematics.

To facilitate forming a holistic view, the widest possible aggregation, integration, and abstraction of pieces of information are needed with regard to all constituents (things, attributes, relations and implications) towards a deep semantic synthesis. Otherwise, a problematics remains a discrete combinatorial composition of its foundational constituents, but compositional characteristics will not be captured. These mechanisms have also been studied in the context of converting data into knowledge, according to the knowledge-pyramid model (Jennex and Bartczak 2013). An inherent feature of problematics is that they show a large number of compositional characteristics, which should be treated as such. As an epistemological conclusion, the constituents of a problematics must be treated both on an instance-level and on a compositional-level. A specific aggregation of the constituents of a problematics on a compositional-level has been dubbed as a cluster. The set of information related to a cluster of constituents lend itself to integration and abstraction towards higher level concepts. These can also be ideated and specified based on intuitionist thinking, which underpin the formulation of general/abstract (GA) things, attributes, relations, and implications. Thus, one form of generating GA concepts is aggregation of instances into clusters and applying generalization on these combinations. Another form of generating GA concepts is semantic/logical reasoning (abstraction) over high-level concepts. An instance manifestation can be derived by actualization of a broader semantic relationship of a generalized cluster or abstract concept means, see Figure 1.

Based on the above reasoning, the RM of an overall research problematics (ORP) will have instance-level things (ITs), attributes (IAs), relations (IRs), and implications (IIs), as well as general/abstract things (GATs), attribute (GAAs), relations (GARs), and implications (GAIs), as its constituents. The instance-level specifications concern constituents physically observable in the physical space, while generalized/abstracted specifications exist in the conceptual/logical space. The specifications of the latter constituents of a problematics are abstract dispositions which convey holistic (higher than instance-level, and non-decomposable and not-reducible) information. The GAAs are associated with GATs in the same way as instance attributes are associated with instance things. The logical scheme shown in Figure 1 brings these constituents together as transitive and bijective semantic relations between the instance and general/abstract constituents of a problematics. Based on this information, Figure 2 shows the conceptual framework of a RM applicable to regular (i.e., non-chaotic) problematics. The GATs, characterized by their unique GAAs, lend themselves to logical/semantic GARs in the mental realm of their interpretation. Depending on their manifestations and attributes, certain GATs may be involved in multiple relations. Based on their logical/semantic relationship they form a scarcely connected network. Therefore, these relations can be regarded as abstract associative interactions. The abstract

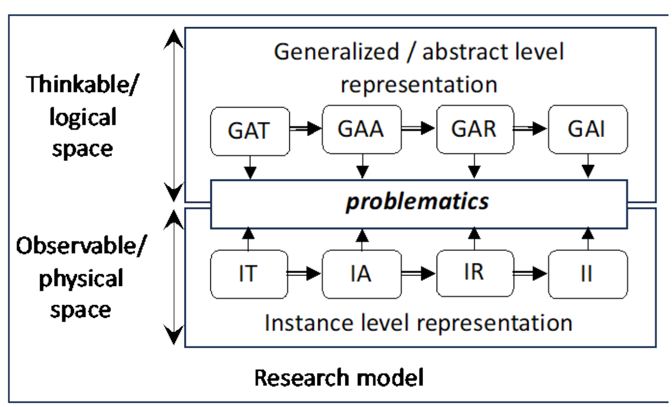

Figure 2: Conceptual framework of a research model developed for a problematics.

associative interactions of GATs obey the rule of causality. If the GATs interact, then there is an implication that appears - as determined by their attributes and relations - in the form of an individual or multiple potential effect or effects. Jointly described by the word 'implication', these are interpreted in the logical/semantic space (rather than in the physical space of spatial, temporal, and substantial metrics).

The above reasoning suggests that not only things, attributes, relations, and implications play an important role in the process of systematically mapping an ORP, but also the 'association' → 'interaction' → 'implication' chain of relations. Specifically, (instance and general/abstract) attributes contribute to the specification of both the manifestation of things, and their possible relations and implications. The nature of the associative relations among the interacting attributed things influences their implications. There are three fundamental mechanisms behind the 'association' → 'interaction' → 'implication' chain of relations. In the order of importance, they are: (i) conceptual determinism, (ii) semantic correspondence, and (iii) commonsensical causality. These higher-level semantic mechanisms make it possible for the GATs, GAAs, and GARs to have such holistic (explicit and implicit) implications from the perspective of the constructed overall RM, which are not conveyed by - and are partially independent from - the implications of the ITs, IAs, and IRs.

Among others, Güvenen (2016) argued that traditional research methods are not sufficient to deal with highly complex questions of modern world and called the attention to the information distortion phenomenon that is caused by the huge amount of not genuine data produced and distributed through modern communication channels. The semantic mechanisms are needed that minimize information distortion by reducing analytic complexity and corrective filtering. The developed method, called holistic systematic combinatorial scoping (HSCS), operationalizes all of the above aspects and assumptions of the conceptual platform. The specific objectives of the HSCS method are to (i) support management of complicated problematics, (ii) rationalize the execution process of holistic investigation, and (iii) systematize the information processing by simultaneous use of instant and general/abstract-level pieces of information. On the other hand, HSCS is challenged by the limitations of strategic anticipation of changes in the descriptive characteristics and volatile manifestation of complicated problematics over a longer period of time (i.e., decades).

The procedural structure of the HSCS includes a total of 21 steps, as illustrated in Figure 3. Logically, these steps are organized into four interrelated blocks of activities: Activity block 1 involves step 1, in which the overall research problematics is delimited, and the general objective is defined. Activity block 2 encompasses steps 2 to 8 and deals with identification and combination of specific instance constituents. Activity block 3 includes steps 9 to 16 and takes care of specification and combination of general/abstract constituents. Finally, activity block 4, which comprises steps 17 to 21, focuses on deriving content for concrete DRPs and transferring them into a coherent RM. In order to (i) cast light on the underlying principles, (ii) support a deeper understanding of the procedure, and (iii) facilitate practical application, we will discuss the HSCB-method through a moderate-complexity practical example.

This demonstrative example is about the problematics caused by accidents frequently happening at an uncontrolled junction (road intersection) in the suburb of a city (see Figure 4). Each step of the application process will be accompanied by a theoretic explanation and further elucidated by the demonstrative example of the simplified real-life problematics in the coming sub-sections, to provide practical guidance. It is believed that the theoretic clarification and the

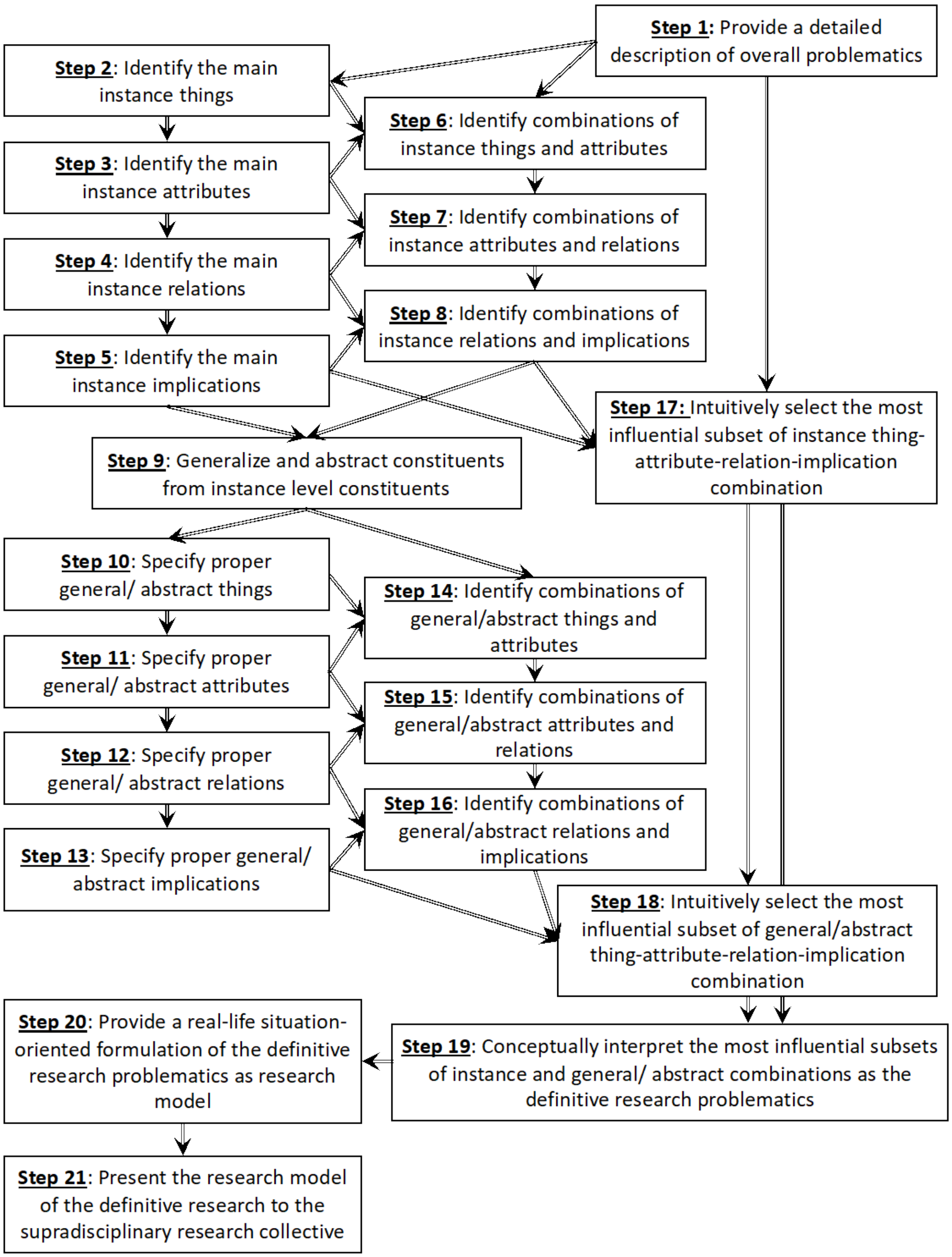

Figure 3: Procedural framework for holistic systematic combinational breakdown.

abridged practical examples in combination will yield a sufficient comprehension both of the conceptual framework and the systematic execution of the HSCB-method in the case of real-world problematics of arbitrary complexity. For the sake of completeness, it must be mentioned that our underpinning work and its results have been included in a research report (RR) that can be accessed at the following link: https://doi.org/10.13140/RG.2.2.22179.84003.

Figure 4: An illustrative image of the concerned uncontrolled intersection in the suburb.

3 Circumscription of Modeling Overall Research Problematics

This activity block involves only an individual step presented below:

Step 1:

The goal of this step is to set the stage for the subsequent steps of the execution HSCS method by establishing a clear and well-defined starting point. It is driven by the assumption, that an effective execution is rooted in a solid understanding of the initial research problematics. In the context of the chosen application scenario, we have generated the following simplified description:

Accidents are frequently happening at an uncontrolled road intersection (junction) in a suburban part of a city (see Figure 4). This uncontrolled intersection does not have any traffic control systems, such as stop signs, yield signs, pavement markings, traffic lights or authorized persons directing traffic, to help determine the right-of-way. When there are no traffic signs or traffic signals to indicate who should proceed first, all vehicles must be driven with caution, and the so-called right-hand rule applies. This is the regulation, but why the real life is so much different?

4 Identification and Combination of Instance Constituents

This activity block comprises seven interlinked steps presented below. Due to the interconnectedness and interdependence of some of its steps (3 and 6, 4 and 7, 5 and 8), they will be presented in combination. The application and execution of these steps in the case of the chosen ORP leads to the following results:

Step 2:

We start the execution by determining the types of things which can be observed to be involved or can be supposed to be involved in an accident (or, let alone, in a dangerous situation), in the neighborhood of the road intersection. A category-oriented classification of the types of things relevant to this traffic-induced ORP is provided below, including their textual and symbolic specifications:

Roads { road, street, boulevard, avenue, driveway, intersection } → [IT_{R1}, …, IT_{R6}]

Additions { sidewalk, crosswalk, bike lane, overpass } → [IT_{A1}, …, IT_{A4}]

Vehicles	{ sedan, hatchback, SUV, coupe, pick-up, semi-truck, box-truck, tractor, motorcycle, sport bike, traditional bike, electric bike, minibus, city bus, touring bus, tram, taxi, police car, ambulance, fire truck, construction vehicle, garbage truck, street sweeper } ⇒ [IT_{V1}, …, IT_{V23}]
Drivers	{ car driver, truck driver, motorcycle rider, bicycle rider, bus driver, tram driver, taxi driver } ⇒ [IT_{D1}, …, IT_{D7}]
Pedestrians	{ adult pedestrian, child pedestrian, elderly pedestrian } ⇒ [IT_{P1}, …, IT_{P3}]
Buildings	{ school building, apartment building, villa, single-family home, duplex, terraced house, rowhouse, mansion, cottage } ⇒ [IT_{B1}, …, IT_{B9}]
Commons	{ children playground, recreation park, memorial park, schoolyard } ⇒ [IT_{C1}, …, IT_{C4}]
Signs	{ stop sign, yield sign, speed limit sign, no entry sign, pedestrian crossing sign, school zone sign, warning sign, informational sign } ⇒ [IT_{S1}, …, IT_{S8}]
Lightings	{ streetlight, traffic light signal, emergency traffic signal, pedestrian crossing light, crosswalk light, bollard light, solar-powered light } ⇒ [IT_{L1}, …, IT_{L7}]

To end up with a size-wise manageable RM, we consider the following conditions: (i) heavy vehicles are not supposed to use the roads crossing in the intersection, (ii) there are no bike lanes next to the roads, and (iii) there are no neighboring buildings, schools or habitation, which would play a role in the occurrence of accidents. For these reasons, the related instance things can be left out from the development process of the RM. In addition, since the intersection is formed by two roads (and not by boulevard, avenue, etc.) and it is not equipped with any traffic control systems, neither the instances of these will be considered. Lastly, taxi cabs, police cars, ambulances, fire trucks, construction vehicles, garbage trucks, and street sweepers are also ignored because, according to related statistics, they have hardly ever been involved in accidents at the studied crossing. This way, relying on all objective (factual) and subjective (intuitive) considerations, a shortened list of highly relevant ITs can be taken inti account that, nevertheless, safeguards the goals of the intended inquiry:

- For (R): two roads are involved, represented as $IT_{R1,1}$ and $IT_{R1,2}$.
- For (V): four sedans ($IT_{V1,1}$, $IT_{V1,2}$, $IT_{V1,3}$, $IT_{V1,4}$), 3 hatchbacks ($IT_{V2,1}$, $IT_{V2,2}$, $IT_{V2,3}$), 2 SUVs ($IT_{V3,1}$, $IT_{V3,2}$), 2 coupes ($IT_{V4,1}$, $IT_{V4,2}$), 1 pick-up ($IT_{V5,1}$), 2 motorcycles ($IT_{V9,1}$, $IT_{V9,2}$), 2 sport bikes ($IT_{V10,1}$, $IT_{V10,2}$), and 2 city buses ($IT_{V14,1}$, $IT_{V14,2}$).
- For (D): 12 car drivers ($IT_{D1,1}$, $IT_{D1,2}$, $IT_{D1,3}$, $IT_{D1,4}$, $IT_{D1,5}$, $IT_{D1,6}$, $IT_{D1,7}$, $IT_{D1,8}$, $IT_{D1,9}$, $IT_{D1,10}$, $IT_{D1,11}$, $IT_{D1,12}$), 2 motorcycle riders ($IT_{D3,1}$, $IT_{D3,2}$), 2 bicycle riders ($IT_{D4,1}$, $IT_{D4,2}$), and 2 bus drivers ($IT_{D5,1}$, $IT_{D5,2}$).
- For (P): four adult pedestrians ($IT_{P1,1}$, $IT_{P1,2}$, $IT_{P1,3}$, $IT_{P1,4}$), 3 child pedestrians ($IT_{P2,1}$, $IT_{P2,2}$, $IT_{P2,3}$), 3 elderly pedestrians ($IT_{P3,1}$, $IT_{P3,2}$, $IT_{P3,3}$).
- For (L): two chandeliers ($IT_{L1,1}$, $IT_{L1,2}$)

Steps 3 and 6 in combination:

No matter if they are chosen based on observation or intuitively/rationally, the selected ITs will become concrete if they are characterized by their respective IAs. Obviously, an exhaustive characterization of the ITs would need infinite number of IAs. Due to this infiniteness, simplification was needed in this context too. Accordingly, only the main IAs of the selected ITs have been taken into consideration. The complete list of IAs used for characterization of the considered ITs can be found in the RR. We have symbolized the associations of IAs as follows: $IA(IT)_{i=[1,n]}$, where the lower index "i" identifies the elements of the set of IAs associated with a particular IT. We have specified a total set of 340 IAs associated with the previously listed 50 ITs. Below, only some representative examples of the symbolic and textual specification of these IAs are given:

$\bigcup_{a=1}^{9} IA(IT_{R1,1})_a$ :: { [Vrouw Avenweg]; 'through-traffic road'; 'is 6m width'; 'has 2 lanes'; 'has asphalt cover'; 'has 50km/h max'; 'is highly cracked'; 'has busy flows'; 'available 24 hours daily' }

$\bigcup_{b=1}^{9} IA(IT_{V1,1})_b$ :: { [60-PJR-3]; 'is sedan'; 'is a Toyota Camry'; 'is on Vrouw Avenweg'; 'is on lane 1'; 'has a good condition'; 'is driving at 50km/h'; 'regularly appearing between 06:00 and 08:00'; 'regularly appearing between 17:00 p.m. and 20:00' }

$\bigcup_{c=1}^{8} IA(IT_{D1,1})_c$ :: { [Melanie]; 'is a female driver'; 'is 33 years old'; 'has 60-PJR-3'; 'is on Vrouw Avenweg'; 'has 15 years of experience'; 'does impaired driving'; 'has 0640587968' }

$\bigcup_{d=1}^{9} IA(IT_{P1,1})_d$ :: { [Gijs]; 'is an adult pedestrian'; 'is a male'; 'is 45 years old'; 'is on Vrouw Avenweg'; 'is crossing'; ' uses his phone'; 'regularly appearing between 07:30 and 08:00; 'regularly appearing between 17:00 and 18:30' }

$\bigcup_{e=1}^{8} IA(IT_{L1,1})_e$ :: { [Chandelier#47]; 'is a streetlight'; 'is on Kalvinstraat'; 'is north of the intersection'; 'is 25m from the intersection'; 'is in good working condition'; 'available 24 hours daily', 'is on from 18:00 to 08:00' }

Steps 4 and 7 in combination:

The goal is to capture the main IRs of the ITs characterized by their respective IAs. IR_i symbolizes a particular relation which is formed by a composition (**ʘ**) of the involved attributed ITs. IR can be self-reflective relation, meaning that it can manifest as a relation between an IT and itself, or it can be an n-ary relation between two or more ITs. Also, in some cases, an IR_x can be dependent from another relation IR_y (as an example, see IR_{20} below). It is important to mention that an IR may not include all IAs associated with the involved ITs, but only those which indeed lead to the existence of the particular IR. In this step too, simplifications are to be applied based on the assumed or observed importance of IRs. For instance, as the streetlights ($IT_{L1,1}$, $IT_{L1,2}$) are supposed to be appropriately placed and to be in good working condition, they do not need to be included in the RM as contributors to influential relations. Based on the application scenario, we have developed a set of 92 IRs. The complete list of determined IRs can be found in the RR. Below is a sample list of IRs, also including the concerned ITs and the associated IAs:

IR_1 =: ʘ { $IT_{R1,1}$; $IT_{R2,1}$ }: [levelled junction] *((formed by))* $IA(IT_{R1,1})_1$, $IA(IT_{R1,1})_9$, $IA(IT_{R1,2})_1$ and $IA(IT_{R1,2})_9$.

IR_2 =: Θ { $IT_{D1,1}$; $IT_{V1,1}$; $IT_{R1,1}$}: [impaired driving experience] *((formed by))* $IA(IT_{D1,1})_1$, $IA(IT_{D1,1})_4$, $IA(IT_{D1,1})_7$, $IA(IT_{V1,1})_1$, $IA(IT_{V1,1})_4$, $IA(IT_{V1,1})_8$, $IA(IT_{V1,1})_9$, $IA(IT_{R1,1})_1$, and $IA(IT_{R1,1})_9$.

IR_{20} =: Θ { IR_1 ; $IT_{V1,1}$}: [approach to intersection] *((formed by))* IR_1, $IA(IT_{V1,1})_1$, $IA(IT_{V1,1})_4$, $IA(IT_{V1,1})_7$, $IA(IT_{V1,1})_8$, and $IA(IT_{V1,1})_9$.

IR_{53} =: Θ { $IT_{P1,1}$; $IT_{R1,1}$}: [inattentive road crossing] *((formed by))* $IA(IT_{P1,1})_1$, $IA(IT_{P1,1})_5$, $IA(IT_{P1,1})_6$, $IA(IT_{P1,1})_7$, $IA(IT_{P1,1})_8$, $IA(IT_{P1,1})_9$, $IA(IT_{R1,1})_1$ and $IA(IT_{R1,1})_9$.

IR_{73} =: Θ { $IT_{V1,1}$; $IT_{R1,1}$}: [encountering cracks] *((formed by))* $IA(IT_{V1,1})_1$, $IA(IT_{V1,1})_4$, $IA(IT_{V1,1})_8$, $IA(IT_{V1,1})_9$, $IA(IT_{R1,1})_1$, $IA(IT_{R1,1})_7$ and $IA(IT_{R1,1})_9$.

Steps 5 and 8 in combination:

The goal of this step is to identify all important observable or expectable (direct and indirect) implications of the various combinations of the most influential ITs, IAs, IRs. According to the causality principle, a particular II takes place if certain relations (IRs) of the concerned attributed ITs concurrently exist. It is important to mention that a combination of IRs may result in more than one II. In our research, a set of 25 IIs has been inferred, which are all listed in the RR. Below a restricted sample of these IIs is presented, including their underpinning IRs and textual specifications:

II_2:: IF {IR_8 AND IR_{15} AND IR_{45} } THEN [Rear-end collision]
//*Explanation*: The condition part is true when IR_8 AND IR_{15} AND IR_{45} instance relations exist with the attributes: $IA(IT_{V2,3})_8$= $IA(IT_{V9,2})_7$ = $IA(IT_{V4,2})_8$ or at $IA(IT_{V2,3})_9$= $IA(IT_{V9,2})_8$ = $IA(IT_{V4,2})_9$.//

II_4:: IF { IR_2 AND IR_{20} AND IR_{37} AND IR_{52} } THEN [T-bone collision]
//*Explanation*: The condition part is true when IR_2 AND IR_{20} AND IR_{37} AND IR_{52} instance relations exist with the attributes: $IA(IT_{V1,1})_8$ = $IA(IT_{V14,2})_6$ or at $IA(IT_{V1,1})_9$ = $IA(IT_{V14,2})_7$.//

II_{25}:: IF { IR_2 AND IR_{20} AND IR_{37} AND IR_{52} } THEN [Vehicles damage]
//*Explanation*: The condition part is true when IR_{75} AND IR_{79} instance relations exist with the attributes: $IA(IT_{V1,1})_8$ = $IA(IT_{V14,2})_7$ or at $IA(IT_{V1,1})_9$ = $IA(IT_{V14,2})_7$ (i.e., at the same time).//

5 Specification and Combination of General/Abstract Constituents

This activity block comprises eight interconnected steps as presented below. Due to their close connectedness and dependency, we present the following steps in a combined form: (i) steps 9 and 10, (ii) steps 11 and 14, (iii) steps 12 and 15, and (iv) steps 13 and 16. The execution of these steps in the case of the chosen problematics, we obtain the following results:

Steps 9 and 10 in combination:

In these steps we focus on the GATs that have been relevant for the comprehensive study of the ORP. Taking a holistic approach, we move beyond thinking about things in the physical world. Here, we explore things, which are related to ORP, exist in the logical space only, but they affect the physical space. Thinking rationally, and somewhat more abstractly, about these constituents allows us looking beyond what is tangible in the real world. For instance, it allows extending our view on the traffic situation based on knowledge of similar traffic situations and extends our inferring towards a holistic understanding. We have considered a limited set of the types of GATs as (supposedly) involved in an accident or in a dangerous situation nearby the road intersection. The types, the concerned GATs and their textual specifications are given below:

Roads	{ poor road condition } ⇾ [$GAT_{R,1}$]
Vehicles	{ poorly maintained vehicle, over-speeding vehicle } ⇾ [$GAT_{V,1}$, $GAT_{V,2}$]
Drivers	{ distracted driver , provocative driver's behavior } ⇾ [$GAT_{D,1}$, $GAT_{D,2}$]
Circumstances	{ heavy rain, tailgating, impaired driving } ⇾ [$GAT_{C,1}$, $GAT_{C,2}$, $GAT_{C,3}$]

Steps 11 and 14 in combination:

In these steps, the GAAs of the selected GATs are specified in an intuitive manner. The essence of selection is similar to "step 3 and 6 in combination", but the reasoning takes place in the rational (thinkable) space. A GAA is symbolically represented as $GAA(GAT)_{j=[1,m]}$, where the lower index "j" identifies the elements of the set of GAAs associated with a particular GAT. We have derived a total set of 38 GAAs which are associated with the previously listed eight GATs. They are detailed in the RR. Below, only a limited list of the various representative GAAs is given, including the GATs they belong to, and their symbolic and textual specifications:

$\bigcup_{a'=1}^{4} GAA(GAT_{R,1})_{a'}$ ::{ 'inadequate road maintenance'; 'remarkable debris on the road'; 'presence of obstacles'; 'bad road surface' }

$\bigcup_{b'=1}^{5} GAA(GAT_{V,1})_{b'}$ ::{ 'malfunctioning vehicle'; 'compromised brakes'; 'worn tires'; 'mismatched body panels'; 'visible external damage' }

$\bigcup_{c'=1}^{5} GAA(GAT_{D,1})_{c'}$ ::{ 'gender'; 'diversion of attention'; 'reduced reaction time'; 'impaired driving performance'; 'low responsibility' }

$\bigcup_{d'=1}^{6} GAA(GAT_{C,1})_{d'}$ ::{'high intensity of raindrops'; 'petrichor'; 'hydroplaning'; 'aquaplaning'; 'loud noise'; 'pooling of water'}

Steps 12 and 15 in combination:

Likewise in the combined steps 4 and 7, the goal of executing these steps is to capture the main GARs of the GATs characterized by their respective GAAs. GAR_i represents a relation formed by a composition (**ʘ**) of all attributed GATs. In this step, simplifications are to be applied based on the assumed importance of the GARs. It is of importance that GARs can also be self-reflective, or they can be formed by two or more GATs. Based on the application scenario, we developed a set of 17 GARs, all available in our RR. Below, some representative GARs are specified:

GAR_1 =: ʘ { $GAT_{D,1}$; $GAT_{R,1}$ }: [dangerous traffic situation due to deficiencies] *((formed by))* $GAA(GAT_{D,1})_2$, $GAA(GAT_{D,1})_3$, $GAA(GAT_{D,1})_4$, $GAA(GAT_{R,1})_2$, $GAA(GAT_{R,1})_3$ and $GAA(GAT_{R,1})_4$.

GAR_5 =: ʘ { $GAT_{D,1}$; $GAT_{C,2}$}: [dangerous traffic situation due to violation of rules] *((formed by))* $GAA(GAT_{D,1})_2$, $GAA(GAT_{D,1})_3$, $GAA(GAT_{D,1})_4$, $GAA(GAT_{C,2})_1$ and $GAA(GAT_{C,2})_2$.

GAR_{16} =: Θ { $GAT_{C,2}$; $GAT_{C,1}$}: [dangerous traffic situation due to circumstances] *((formed by))* $GAA(GAT_{C,2})_1$, $GAA(GAT_{C,2})_2$, $GAA(GAT_{C,2})_3$, $GAA(GAT_{C,1})_3$ and $GAA(GAT_{C,1})_4$.

Steps 13 and 16 in combination:

The goal of this step is to intuitively determine and identify all important GAIs implied by the various combinations of the most influential GATs, GAAs and GARs. GAIs will take place if a number of relations happen at the same time. Similarly to the generation of IIs, the combination of GARs can lead to more than one GAI. We disclosed a set of 78 GAIs, all specified in RR. Below is an illustrative sample of GAIs, the underpinning GARs, and the textual specifications are provided:

GAI_3:: IF { GAR_5 AND GAR_7 } THEN [tailgating chaos]
//Explanation: tailgating chaos implication may emerge when dangerous traffic situations on the road occur due to the involvement of several vehicles in tailgating.//

GAI_{28}::IF { GAR_1 AND GAR_{15} } THEN [distraction hazard]
//Explanation: distraction hazard implication may emerge when dangerous traffic situations on the road occur due to the maneuvers of one or more distracted drivers.//

GAI_{63}::IF { GAR_2 AND GAR_8 } THEN [weather peril]
//Explanation: weather peril implication may emerge when dangerous traffic situations on the road occur due to the influence of the weather conditions.//

GAI_{71}::IF { GAR_1 AND GAR_6 } THEN [maintenance neglect amplification]
//Explanation: maintenance neglect amplification may emerge as implication when dangerous traffic situations on the road occur due to failure or omission of regular maintenance activities that are necessary to keep vehicles properly working.//

6 Derivation of Definitive Research Problematics and Elaboration of Research Model

In activity block 4, five steps have been completed, as discussed below:

Steps 17:

This step is about the intuitive finding and selection of a subset of the instance thing-attribute-relation-implication (i-TARI) combinations, which are the most influential to resolve the so-called initial research problematics (IRP). While ORP previously presented is broad, indefinite, and not described from a content point of view, IRP is less broad, definite, and specified in terms of content. In this step, the relevant i-TARI combinations are included in one or more scoped research problematics. In principle, the total number of i-TARI combinations could be derived by the combinatorial Equation 1:

$$\prod = \{(\frac{n_{IT}!}{m_{IT}!\times(n_{IT}-m_{IT})!}) \times (\frac{n_{IA}!}{m_{IA}!\times(n_{IA}-m_{IA})!}) \times (\frac{n_{IR}!}{m_{IR}!\times(n_{IR}-m_{IR})!}) \times (\frac{n_{II}!}{m_{II}!\times(n_{II}-m_{II})!})\}, \tag{1}$$

where n_{IT}, n_{IA}, n_{IR}, and n_{II} are the total number of ITs, IAs, IRs, and IIs characterizing the investigated IRP, and m_{IT}, m_{IA}, m_{IR}, and m_{II} are the number of ITs, IAs, IRs and IIs selected for the RM. The objective is to discern those constituents and their semantical interrelationships which are meaningful for deriving multiple scoped research problematics (SRP) by reducing the IRP, and constructing manageable DRP and specific RMs. This is a knowledge-intensive process, which is influenced by the objective and subjective decision/preference of the investigator.

We have used a back-tracking reasoning to the traffic scenario to select interrelated attributed ITs, which can be supposed to provide explanation on the reason why accidents occur around the uncontrolled intersection, as well as on their nature. In this context, those IIs have been taken into consideration which are explicitly related to accidents, namely (II_2) [rear-end collision], (II_3) [head-on collision], and (II_4) [T-bone collision]. The remaining IIs have been excluded. Based on a similar reasoning, we have eliminated IR_{20} and IR_{37} because they share the same ITs, IAs and IIs and they are also indirectly included in IR_{52} that deserves further studies. Some of the listed ITs may be involved in traffic accidents, but they may not be the primary causes of them, such as $IT_{D3,2}$, $IT_{V9,2}$, $IT_{V14,2}$. $IT_{R1,1}$, and $IT_{R1,2}$. Furthermore, certain ITs having time-conditioned attributes can be eliminated since their timing may exclude their concurrent occurrence. Eventually, these filtering actions reduce the overall complexity of capturing the essence of an IRP and facilitate its simplified but purposeful modeling using the most influential i-TARI combinations, as illustrated in Figure 5.

Steps 18:

This step concerns the intuitive selection of a specific subset of the most influential general/abstract thing-attribute-relation-implication (ga-TARI) combinations for the RM to support obtaining new knowledge from a holistic perspective for the IRP. Towards this end, we analyzed the ga-TARI constituents to explore those indeed associated with traffic accidents. Accordingly, we have eliminated those ga-TARI combinations which are associated with exceptional circumstances, such as rain, etc. We also eliminated GAI_1, GAI_2, GAI_{54}, …, GAI_{62} to remove redundancies, since these GAIs represent a combination of other considered GAIs. At removing redundancies, we have also excluded ga-TARI constituents which are dependent on the already excluded ga-TARI combinations. The result is shown in Figure 6.

Steps 19:

As the outcome of completing Steps from 2 until 18, a conceptual framework of the SRP, including a limited number of i-TARI and ga-TARI constituents, is available for further processing. The ultimate objective of this step is to provide a real-life-conform and social stakeholders-orientated textual, video, or mixed rendering of the preferred DRP, and to facilitate arriving at a RM which combines both symbolic and non-symbolic forms. Towards this end, a necessary step is to transcribe the symbolic structures of the various possible DRPs into verbal/textual descriptions in a comprehensive but transparent manner. It must be mentioned that the considered cross-level thing, attribute, relation, and implication constituents represent only a part of the IRP, which we refer to as SRP. Towards this end, the content (the various constituents and their interconnections) should be conceptually

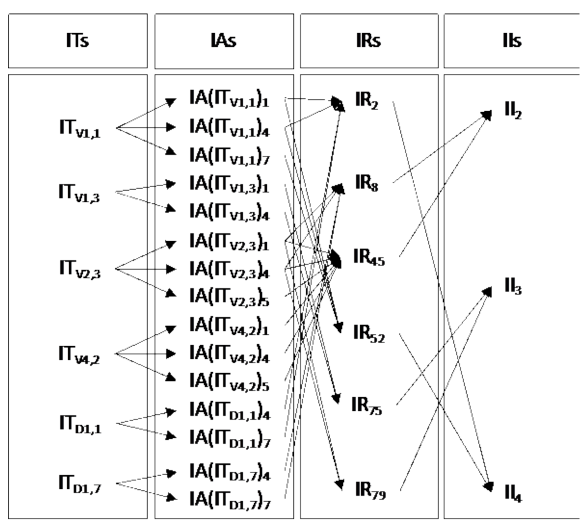

Figure 5: The considered most influential i-TARI combinations.

interpreted and depicted by phrases. This is referred to as conceptualization (C). Based on the conceptual framework of the SRPs, multiple conceptualizations are possible. We have used the symbolic formalism shown in Equation 2 to represent the possible holistic conceptualization, C_i, of a SRP:

$$C_i :: C_j^{i-TARI} \oplus C_k^{ga-TARI} \tag{2}$$

where: the lower index "i" identifies the elements of the set of C_is created by the combinations of the jth i-TARI constituents and the kth ga-TARI constituents. In the context of our demonstrative example, we have considered the combinations of three $C^{i\text{-}TARI}$ conceptualizations and three $C^{ga\text{-}TARI}$ conceptualizations as sufficient. For the sake of simplicity, we have represented the possible (derivable) scoped research problematics, marked by Π, symbolically by Equation 3:

$$\Pi = \{\mathrm{IT, IA, IR, II}\} \oplus \{\mathrm{GAT, GAI, GAR, GAI}\} \tag{3}$$

The specification of the SRP is chosen to include six ITs and four GATs, as well as three IIs and three GAIs. This semantic construct is shown in Figure 7, which also displays the derivable nine conceptualizations (C_i), which lend themselves to nine different definitive research problematics - DRPs. Below is an example of the symbolic representation of a particular conceptualization, C_9:

Conceptualization C_9: Π_9 = { ($IT_{V1,1}$, $IT_{D1,1}$), ($IA(IT_{V1,1})_1$, $IA(IT_{V1,1})_4$, $IA(IT_{V1,1})_7$, $IA(IT_{D1,1})_4$, $IA(IT_{D1,1})_7$), (IR_2, IR_{52}), (II_4) } ⊕ { ($GAT_{V,2}$), ($GAT_{D,1}$)), ($GAA(GAT_{V,2})_1$, $GAA(GAT_{V,2})_2$, $GAA(GAT_{D,1})_1$, $GAA(GAT_{D,1})_2$, $GAA(GAT_{D,1})_3$, $GAA(GAT_{D,1})_4$), (GAR_5, GAR_{13}), (GAI_{37}) }

The various, symbolically represented conceptualizations of different DRPs can be semantically interpreted and transcribed into verbal constructs as shown by this example below:

Exposition (Π_9): The definitive research problematics (DRP_9) constitutes in a situation in which a distracted female driver is doing impaired driving and over-speeding – thereby, is creating the hazard of accident nearby the junction.

The complete list of determined Cs and DRPs can be found in the archived RR. Motivated by the personal interest of studying women's behavior, we have decided to choose Π_9 from the possible DRPs and to convert it into a detailed RM based on the above symbolic and verbal/textual representations. The reason is that this is the only DRP that is centered exclusively on the behavior of the female drivers and its influence in causing accidents near the intersection independently from road and vehicle conditions.

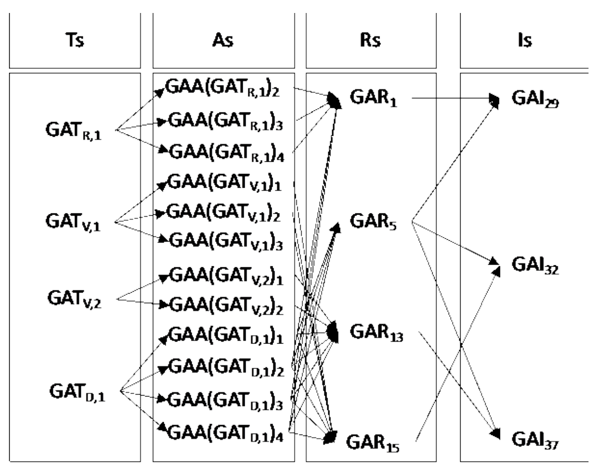

Figure 6: The considered most influential ga-TARI combinations.

Step 20:

The execution of this step aims at converting the symbolic representations and textual/verbal expositions of a DRP into a specific research model which, in simple words, defines what to study. A RM is a theoretical image of the object of study that may have different roles (Palvia et al.

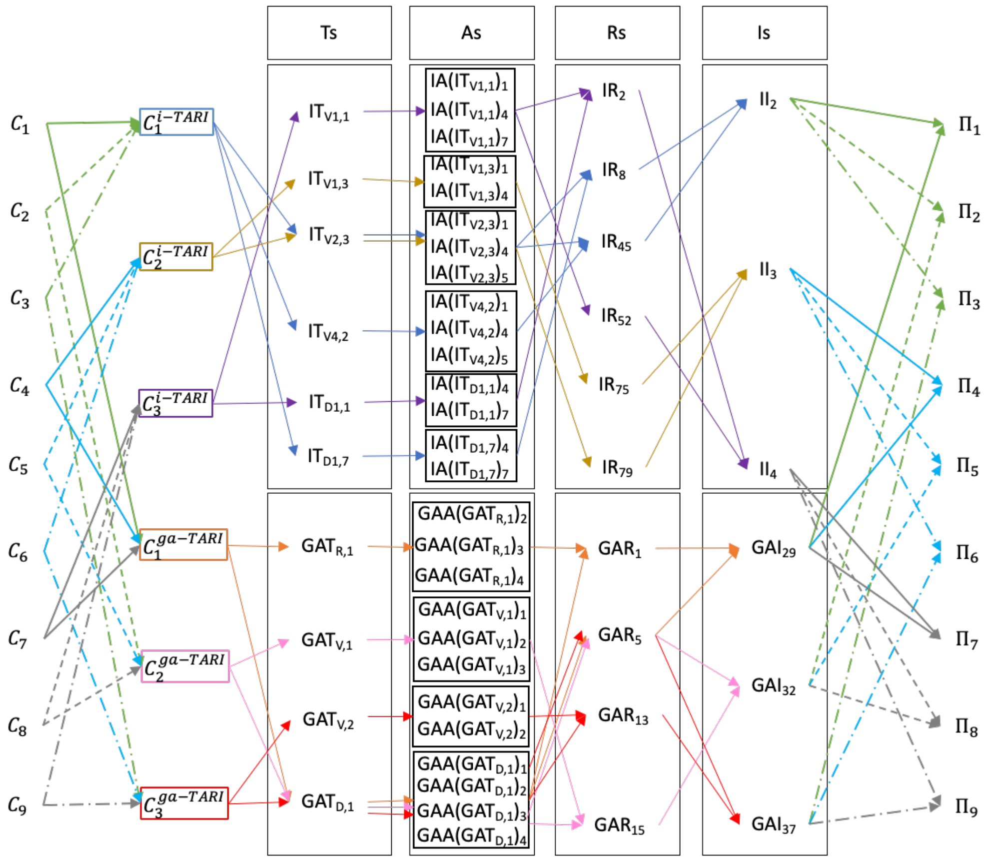

Figure 7: Conceptualization of meaningful DRPs based on the conceptual basis of a particular SRP.

2006). In the case of a DRP, a RM supports (i) the exploration and understanding of the dependences of the different constituents and relationships, (ii) the researcher's choice of research methods, (iii) the nature of the data collected, and (iv) the interpretation of the findings. It can be used to identify various configurations, evaluate probabilities and possibilities, analyze the manifestation and performance, and compare similarities and differences across different cases or scenarios (Jensen and Bard 2002). A RM lends itself to various research questions, research hypotheses, research designs, and research interventions (de Villiers 2005).

The first action in the RM development process is an inventory of what we have learnt about Π_x. The specification of the chosen DRP_9, allows us to state a wide range of research questions (RQs). The situation described by the i-TARI and ga-TARI combinations within DRP_9 relates to the posable RQs. As an example, the above conceptual elements of the RM allow us to ask about the involvement of female drivers in an accident nearby the junction because of one, a combination of, or the total of the following reasons (i) being distracted, (ii) being impaired, and (iii) over-speeding. The succeeding actions are completed according the RM shown in Figure 8. Starting out from the DRP, the next action focusses on the analysis of what input and output research indicators (RIs) and research variables (RVs are needed to capture the i-TARI and ga-TARI included in the DRP.

In the case of inquiries concerning research problematics, it may be challenging to find concrete RVs. In such cases, the use of RIs may be a way out. In the next action, the dependence

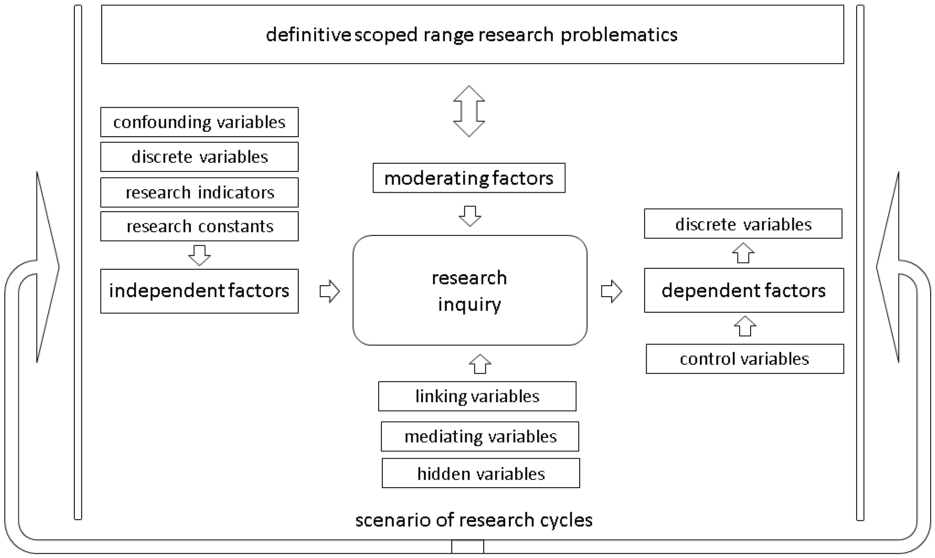

Figure 8: Basics of conversion of definitive research problematics into a detailed research model.

relationships among the independent (predictor) and the dependent (criterion) research descriptors (RDs) are considered in order to find quasi-independent (e.g., linked), non-independent (e.g., confounding), or moderator (e.g., affecting) RDs. Finally, the last action is to provide a visual presentation of the inquiries with regard to the used RDs and their relations, and to conceptually include these inquiries in possible research cycles. Their procedural inclusion is a task for the development of the research design.

Step 21:

Driven by the DRP and the stated specific RQ, an explorative study can be conducted to understand the behaviors associated with female drivers leading to accidents. Toward this end, a number of subordinate RQs need to be answered. The most important ones can be sorted as follows:

- **Behavioral patterns:** (1) Which specific distracted driving behaviors are exhibited by adult female drivers nearby uncontrolled intersections? (2) How do these behaviors, such as tailgating, contribute to the occurrence of accidents?
- **Impairment and driving:** (1) What are the types of impairments among adult female drivers involved in accidents near uncontrolled intersections? (2) How does impaired driving impact decision-making and safety near such intersections?
- **Contextual factors:** (1) Is the environmental condition a common contextual factor with regards to accidents involving distracted and impaired female drivers near the uncontrolled intersection? (2) Is the time of day a common contextual factor with regards to accidents involving distracted and impaired female drivers near the uncontrolled intersection?
- **Safety interventions:** (1) What interventions could be designed to address the specific risks posed by distracted and impaired driving by adult female drivers? (2) What awareness programs could be developed to reduce the specific risks posed by distracted and impaired driving by adult female drivers?

To answer these question, we can methodologically consider (i) analyzing a broader dataset of accidents near uncontrolled intersections to identify patterns and trends related to adult female drivers; (ii) conduct observational studies or use in-vehicle monitoring systems to assess real-time behaviors of adult female drivers near the Vrouw Avenweg and Kalvinstraat intersection; and/or (iii) gather insights through surveys and interviews with adult female drivers to understand their perspectives on distractions, impairment, and driving habits in general. As a representative case, the inquiry on the interplay of distracted and impaired driving among female drivers near the uncontrolled intersection of Vrouw Avenweg and Kalvinstraat requires a SDR approach. Various areas of expertise, including technical, behavioral, and social sciences, are essential to comprehensively address this DRP, such as: (1) *Traffic engineering* needed for analyzing accident data and proposing engineering solutions; (2) *Human psychology* examining female driver behavior essential for designing surveys and behavioral studies; (3) *Public health* analyzing accident data from a public health perspective needed to design new safety programs; (4) *Social sciences* studying how societal expectations may contribute to certain patterns of distracted and impaired female drivers; (5) *Data science* analyzing large datasets of accidents for extracting valuable insights; (6) *Design engineering* designing and implementing technology solutions or interventions to reduce destruction among drivers; (7) *Education* designing effective communication strategies to raise awareness about the risks of distracted and impaired driving between adult female drivers; (8) *Ethics* addressing ethical considerations related to data collection, participant consent, and privacy ensuring that research is conducted responsibly and adheres to ethical standards.

7 Reflections and Conclusions

In our work, problematics have been treated abstracted real life situations that are characterized by transdisciplinarity, mutual dependencies, and compositionality of constituents. They represent challenges for science, research, and development, as well as for society, industries, and businesses. As a detailed procedural scenario, we presented the holistic systematic combinatorial scoping framework that allows the handling of complicated research problematics. The 21 steps of the HSCS method offer a holistic conversion of a vague ORP into a focused, scoped, structured, and concise DRP presented in a research model that can be investigated with different goals and from multiple perspectives by a transdisciplinary research team.

Part 1 of the paper was focused on the foundational issues of provisioning knowledge for deriving manageable research models for supradisciplinary research. Presented in Part 2, the application case (the traffic accident problematics) demonstrates the process of how to get to problematic-specific knowledge which facilitates understanding and finding design solutions for technologically- and socially-rooted complicated problematics by following the steps of the HSCS. The above proves that systematic inquiries are important for design theory and methodology, but also for the practice of designing systems-based solutions for the addressed problematics.

The deployment of the HSCS involved the relatively simple ORP of preventing frequently occurring accidents at an uncontrolled intersection in the suburb of a city. The variety of the constituents and issues discussed also demonstrated why supradisciplinary research efforts have been regarded necessary. By the proposed HSCS method, the ORP could successfully be transformed into a set of nine focused DRPs. The compilation and the analyses of the related i-

TARI and ga-TARI constituents and combinations provided an effective basis for studying the selected demonstrative problematics. This procedure offers not only descriptive information, but also pieces of knowledge that support the assessment of the relevance of constituents. Also, it complements the instance-level information with holistic-level information, and facilitates a combined assessment of such situations, respectively leading to the generation of SRPs. It bears significance because it excludes irrelevant conceptual constituents to the accident situations. Nevertheless, experiences about the applicability (or more precisely, about the needed efforts and the faced cognitive complexity) of the HSCS method are to be gained and this calls for further dedicated studies.

Thanks to the focus on concurrent scoping and enabling holistic reasoning, as well as to its flexible and intuitive content management, the HSCS method offers scientific novelty from the perspective of developing modern research methodologies. The freedom provided by a SRP is an important issue since it lends itself to multiple RMs which can be compared before launching transdisciplinary or supradisciplinary studies. On the other hand, scoping must be treated with care, since it may cause fixation or loss of holism. Taking these into consideration, the HSCS method can eventually offer not only a systematic approach to investigation of complicated problematics but can a more effective way of exploring relevant new knowledge for resolving them. These are considered to be the main advantages in comparison with other methods randomly (non-systematically) deriving RMs. Based on the preference of the most influential combinations of i-TARI and ga-TARI constituents, every SRP serves as a semantic framework for a number of DRPs. The eventually derived DRPs can be converted into RMs by choosing the most appropriate research indicators, research variables, and their causal and correspondence relationships. The result of this systematic procedure can be concisely but effectively presented to transdisciplinary research teams, and activity plans (research designs and research cycles) for new knowledge extraction and synthesis can be purposefully developed based on the derived DRPs and corresponding RM.

8 Propositions and Future Work

The research reported in this paper led to the following main propositions:

- Imposing and benefiting from a holistic view at studying complex socially-rooted problematics require a dedicated methodology that can be applied to a broad array of scientific field and investigational concerns.
- Even the most extensive holistic analysis cannot mean the consideration of all constituents and relationships of a real-life complex problematics because of needed infinite amount of information. Accordingly, intuitive filtering and selection are always needed.
- A research problematics can be supposed to distinguish itself from a naturally-existing phenomenon by its (i) highly complicated nature, (ii) disciplinary heterogeneity, (iii) socio-technological roots, (iv) physical and logical interconnectedness, (v) possible rapid emergence and changes, and (vi) wide-spread implications.
- Time has come for researchers to develop computationally supportable methodological approaches to study and resolve complex, heterogeneous, intricate, or even wicked, industrially or socially created problematics. Future research will tell if computational intelligence and

generative AI methods can be used ate their formal rendering when these problematics reaches the boundaries of human comprehension.

- The complicatedness of a problematics is a result of the several interplaying and dissolved natural or created phenomena and unsolved problems, which cannot be observed, measured, and treated individually due to their confounding, inseparable and abstract nature. Problematics are beyond the investigational coverage of classical mono- and interdisciplinary research approaches.
- We have conjectured and provided evidence that a conceptually and methodologically extended version of the SCB-method, which has initially been proposed for investigation and scoping of naturally existing phenomena, can be applied in investigation, and scaling complicated research problematics.
- Inclusion and forming of a holistic view in HSCS method is achieved in an intentionally simplified manner. It consists of deducing the widest possible aggregation, integration, and abstraction of the pieces of information from i-tari constituents as well as ga-tari constituents towards a deep semantic synthesis and funneling.
- For managing the scope insightful of complicated research problematics and to enable their multi-dimensional transdisciplinary investigation, we propose to use the developed procedural framework and the HSCS method, which can be operationalized based on the scenario offered by 21 activity steps.

The work reported in this paper opens up uncountable new research opportunities. Follow-up research in this direction is very much needed because (i) more and more research problematics are being created, (ii) the currently experienced problematics beg for urgent, comprehensive, and efficient addressing, (iii) the proliferation of the concept of supradisciplinary research needs new methods of research model and research design development. In this perspective, our upcoming research focuses on testing the HSCS in transdisciplinary and supradisciplinary research collectives dealing with complex socially-rooted problematics.

Authors' Contribution: (i) overall: F.-Z. A. E.-B. ~75%, I.H. ~25%, (ii) conceptualization: F.-Z. A. E.-B ~50%, I.H. ~50%, (iii) research report: F.-Z. A. E.-B. ~70%, I.H. ~30%, (iv) paper content: F.-Z. A. E.-B.~70%, I.H. ~30%, (v) structuring: F.-Z. A. E.-B. ~70%, I.H. ~30%, (vi) references: F.-Z. A. E.-B. ~50%, I.H. ~50%, (vii) imageware: F.-Z. A. E.-B.~60%, I.H. ~40%, (viii) lay-outing: F. Z. A. E.-B. ~80%, I.H. ~20%.

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