ANALYSIS AND SYNTHESIS OF RESILIENT LOAD-CARRYING SYSTEMS

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ABSTRACT

Resilient systems have the capability to survive and recover from seriously affecting events. Resilience engineering already is established for socio-economic organisations and extended network-like structures e. g. supply systems like power grids. Transferring the known principles and concepts used in these disciplines enables engineering resilient load-carrying systems and subsystems, too. Unexpected load conditions or component damages are summarised as disruptions caused by nesciense that may cause damages to the system or even system breakdowns. Disruptions caused by nescience can be controlled by analysing the resilience characteristics and synthesising resilient load-carrying systems. This paper contributes to a development methodology for resilient load-carrying systems by presenting a resilience applications model to support engineers analysing system resilience characteristics and behaviour. Further a concept of a systematically structured solution catalogue is provided that can be used for the classification of measures to realise resilience functions depending on system adaptivity and disruption progress. The resilience characteristics are illustrated by 3 examples.

Keywords: Resilience, Load-carrying systems, Complexity, Uncertainty, Product modelling / models

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1 INTRODUCTION

Resilience is known as a vital concept of living organisms. Living organisms are not only resistant to e.g. cold or heat but are able to heal severe diseases or injuries and live on despite the loss of organs. Resilience characteristics and behaviour have been adapted in many disciplines to describe the ability of engineered systems to survive major crises and adapt to changes in their global, changing environment. Engineers aspire to transfer the concept of resilience characteristics to system design. Currently most technical systems are robust towards presumed influences due to their design. Though not envisaged usage scenarios like unexpected load conditions and disturbances or unforeseen system conditions like component failures often reduce the system's performance dramatically or can even cause a total system breakdown.

Looking at load-carrying systems like e.g. a tyre unexpected disruptions could be adverse weather conditions like black ice or a puncture of the tyre. Due to these disruptions the car is not able to keep up full stability and velocity of the vehicle or an accident can occur. Measures to cope with these disruptions currently are snow chains for black ice or a spare wheel in case of a puncture. Nevertheless, those technical system do neither allow to use the measure autonomously nor do they recover by themselves. In contrast some engineered systems like socioecological organisations or wide spread networks like power grids are known for showing resilient behaviour (Hollnagel and Woods, 2010). For the development of those systems the analysis of accidents, incidents and risks is of particular interest. Engineering resilient technical systems in general focuses on unexpected external disturbances as well as internal damages (Jackson, 2016).

Designing load-carrying systems in particular striving for resilient system properties means a paradigm shift. The focus during designing resilient systems is on maintaining a minimum functionality in case of disruptions and regaining full functionality afterwards. During the development of resilient load-carrying systems the specific challenges are that flexibility and resources of load-carrying systems are severely restricted and the systems are exposed to divers influences or suffer from partial failures. While robust systems only perform under predetermined conditions, resilient systems aim for the avoidance of a total breakdown in order to avoid critical, dangerous situations and the high effort of mending the occurred damage.

Robust load-carrying systems are designed to withstand varying load conditions and disturbances in a defined area more or less close to the design point referred to as stochastic uncertainty which is a basically known uncertainty. Unexpected disruptions are principally disregarded during product development. These basically unknown influences are referred to as nescience about the affecting parameters. In general, robust design is not capable of controlling uncertainty caused by nescience. Developing load-carrying systems engineers are able to cope with uncertainty caused by nescience by designing resilient load-carrying systems which are able to ensure continuous functionality of the system and avoid at least catastrophic consequences. (Schlemmer *et al.*, 2018, Hanselka and Platz, 2010, Freund, 2018, Woods, 2010, Ahern, 2011).

As the development of resilient load-carrying systems increases the complexity of the development process a basic understanding and therefore specific basic definitions like resilience metrics and resilience functions are required and approaches for the realisation of resilience in general have to be transferred to load-carrying systems. There already are some design approaches known which are capable of avoiding dangerous situations of load-carrying systems e.g. fail-safe and can be assumed as partly resilient. Designing future resilient load-carrying systems shall exceed the capabilities of fail-safe design by avoiding failures and the ability to recover and regain full or even improved functionality.

Though a comprising methodological framework for the development of resilient load-carrying systems is not available, yet. The main purpose of this paper is to provide a contribution to the methodological development of resilient load-carrying systems. It is intended to deduct a structure to systematise solutions, solution principles or at least solution approaches for realising resilience functions of corresponding systems whereby the applicability depending on the disruption and the desired system behaviour is focused. Some known measures are named and classified within the structure as an example. Using this structured framework with the classified known measures enables the developer to more easily choose measures to be taken into account for his specific system. Beforehand the existing system has to be analysed. Therefore a resilience application model is introduced that helps to depict the system state, the desired system and environmental aspects of interest for the realisation of resilience.

The concrete behaviour of resilient load-carrying systems has been defined by Altherr *et al.* (2018) as a working definition: ‘A resilient [load-carrying] technical system guarantees a predetermined minimum of functional performance even in the event of disturbances or failure of system components, and a subsequent possibility of recovering at least the set point function.’ (Altherr *et al.*, 2018)
The previously mentioned principles are commonly used for safety-systems like run-flat tyres. The expounded theoretical contents of the paper will be explained using the example of the run-flat tyre and a special snow chain system in chapter 5.

2 RESILIENCE CHARACTERISTICS AND RESILIENCE BEHAVIOUR

Starting the design process the developer needs to analyse the current or reference system and define the desired resilience behaviour of the aspired system. (Florin and Linkov, 2016, Ganin *et al.*, 2016)

2.1 Dynamic system properties (resilience behaviour)

The resilience behaviour is time-dependent and thus represents the dynamic properties of the system. It is describable as a chronological sequence following a disruption that can be distinguished into three phases depicted as a graph in Figure 1 (Altherr *et al.*, 2018, Tierney and Bruneau, 2007). First the functional performance drops from its original state during the disruption phase (I) after a disruptive event. Subsequently the system operates in a stable disrupted state throughout phase two (II). During the system recovery phase (III) the functional performance increases to its recovered level. By not dropping below the required minimum functional performance f_{min} a safe operation is guaranteed and a total system breakdown is avoided (Schlemmer *et al.*, 2018).

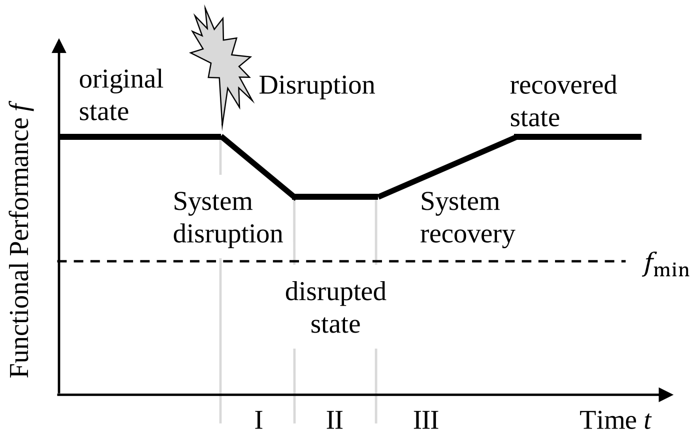

Figure 1: Time-dependent resilient behaviour (referring to Schlemmer et al., 2018)

2.2 Static system properties (resilience characteristics)

However, while the desired time-dependent resilient behaviour mainly should meet the expectations of the system’s user the developer needs static resilience characteristics for designing resilient load-carrying systems. While the resilience behaviour describes the system’s functional performance over time an appropriate description of the desired *static system characteristics* depending on the influencing parameters is needed additionally. In contrast to robust design for designing resilient systems the static system characteristics has to be described and quantified as a relation of the functional performance to the range of influencing parameters.
Concepts for measuring resilience qualitatively and quantitatively already exist though the concepts do not apply for load-carrying systems in particular (Florin and Linkov, 2016, Ganin *et al.*, 2016). Altherr *et al.* developed a set of metrics concerning resilient systems’ characteristics especially of load-carrying systems (Altherr *et al.*, 2018, Hosseini *et al.*, 2016). The resilience characteristics are illustrated and visualised by plotting the functional performance as a function of the influencing factors in Figure 2.
Resilience capabilities are represented by four metrics characterising the curve progress of the graph. The *margin* describes how precarious the system operates with respect to a kind of performance boundary which is shown by the distance between the design point performance and the minimum functional performance f_{min} (Altherr *et al.*, 2018, Woods, 2010). Resilient systems are characterised by the range of influencing factors in which the system is able to perform without total breakdown also

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referred to as loss of integrity. The performance range describes the overall range of values of an influencing parameter that allows operation above the required minimum performance. Whereas the depicted *performance radius* shows the "closest" point of falling below the minimum functional performance related to the design point. When operating close to the performance radius in many cases a sudden breakdown of the system by exceeding the limits is difficult to control and may cause dangerous system conditions. The curve slope near the functional performance radius is defined as gracefulness (also referred to as graceful degradation) (Woods, 2010).

Resilient systems have to be able to cope with both unforeseen working conditions and damages. In case of load-carrying systems the loss of performance caused by component failures is defined as the metric *systemic buffering capacity* depicted in the static resilience characteristics diagram by a lowered curve as shown in Figure 2 (Woods, 2010).

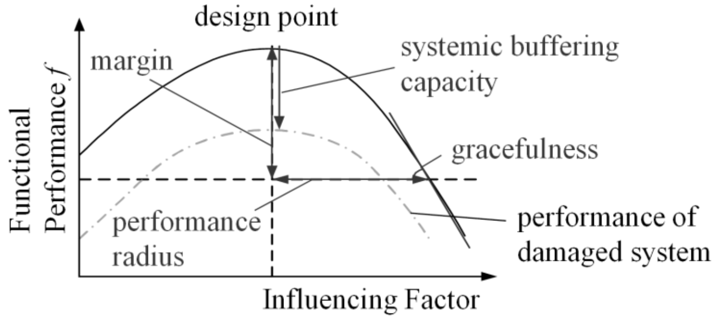

Figure 2: Metrics for the resilient characteristics of a system (referring to Altherr et al., 2018)

2.3 Resilience functions

In resilience engineering the resilience characteristics are often represented by so called resilience functions derived from the cornerstones of resilience (Hollnagel, 2010). Most common is the set of the four resilience functions *respondin*g, *monitoring*, *anticipating* and *learning*. However, these functions have different sense depending on the kind of system and the intended purpose. For instance, the presence respectively absence of these functions may be used to define the system's level of resilience. Designing load-carrying systems resilience functions can be used to determine the basic structure and realisation of the desired resilience characteristics equivalent to technical functions in methodological design (Hollnagel, 2010, Jackson, 2016, Woods, 2010, Hollnagel, 2011, Pahl *et al.*, 2017, Jackson, 2009). A load-carrying system comprising only the resilience function *responding* is able to react to an actual disruption providing best possible static system resilience characteristics in a predefined way and to recover afterwards. The resilience functions *monitoring* and *anticipating* both use the detection, measurement and observation of signals that enable a system to react to a disruption in an improved way. *Monitoring* analysis signals to detect upcoming actual threats and initiates short-term measures to adapt the system's static resilience characteristics in order to guarantee a high functional performance during disrupted state and prevent a system breakdown. *Anticipating* utilizes the analysed signals to prematurely foresee possible disturbances further in the future and prevent damages by responding appropriately in time. Systems *learning* from failures as well as success require constant monitoring of the system and its environment and an intelligent control system that is able to process the data and information. (Madni and Jackson, 2009, Woods and Hollnagel, 2010) Looking at the development of resilient load-carrying systems and especially subsystems the resilience functions *learning* and partially *anticipating* are reserved for highly sophisticated systems.

2.4 Resilience application model for analysing resilient load-carrying systems

Looking at the development of load-carrying systems only analysing and defining static and dynamic resilient system properties like they are given in Figure 4 a) and b) is insufficient to realise the required resilience functions. Knowledge about time dependency of the *disruption intensity* given in Figure 4 c) and a correlated *signal intensity* like in Figure 4 d) are additionally mandatory to initiate a timely and appropriate system reaction.

Disruptions arise from either application scenarios like external disturbances or internal system conditions caused by malfunctions or damages of components (*component failure*). Common disturbances are unpredictable load conditions like overload or unusual influences of temperature, dust

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or corrosives but also natural disasters. (Jackson, 2009, Madni and Jackson, 2009) The system's behaviour depends on extend, duration and velocity of occurrence of a disruption. Therefore the impact of the disruption represented by the *influencing factor* as well as the temporal course of the *disruption intensity* has to be considered determining measures to realise resilience functions.

The ability to *respond* to disruptions requires an action before the actual drop of the functional performance. This requires continuous *monitoring* of the system by watching the *signal intensity* corresponding to the disruption. The ability to *anticipate* assumes that upcoming disruptions can be deducted from monitored signals and the system is able to react appropriate in time e.g. with an *increased systems performance* due to a preventive measure. The resilience function *learning* referring to load-carrying systems is normally reserved to mechatronic systems and requires a connection to an intelligent control system.

Thus information about relations between *functional performance*, *disruption intensity*, *signal intensity* and *time* or *influencing factors* are an elementary prerequisite for designing resilient load-carrying systems. A resilience application model for load-carrying systems was developed as a basis for design methods to support developers, including the four diagrams shown in Figure 4. Designers shall use this model stepwise to analyse the application context and the system behaviour. The analysis starts with the identification of a severe disruption and its time dependent progress (Figure 3 c). To be able to *monitor* or even *anticipate* the disruption a corresponding signal (Figure 3 d) indicating the occurrence, intensity and time-dependent progress according to the disruption itself has to be figured out. The effect of the disruption on the system has to be characterised by influencing factors and estimated as the static resilience characteristics of the system (Figure 3 a). Based on the disruption progress (Figure 3 c) and the static resilience characteristics the estimated dynamic resilience behaviour (Figure 3 b) can be derived and shown as a graph. Using the determined system resilience characteristics designers are able to derive and formulate requirements and also fundamental measures.

The application model can also be used reversely for synthesising resilient load-carrying systems by defining target properties as explained in Figure 3 and deducting specified resilience functions.

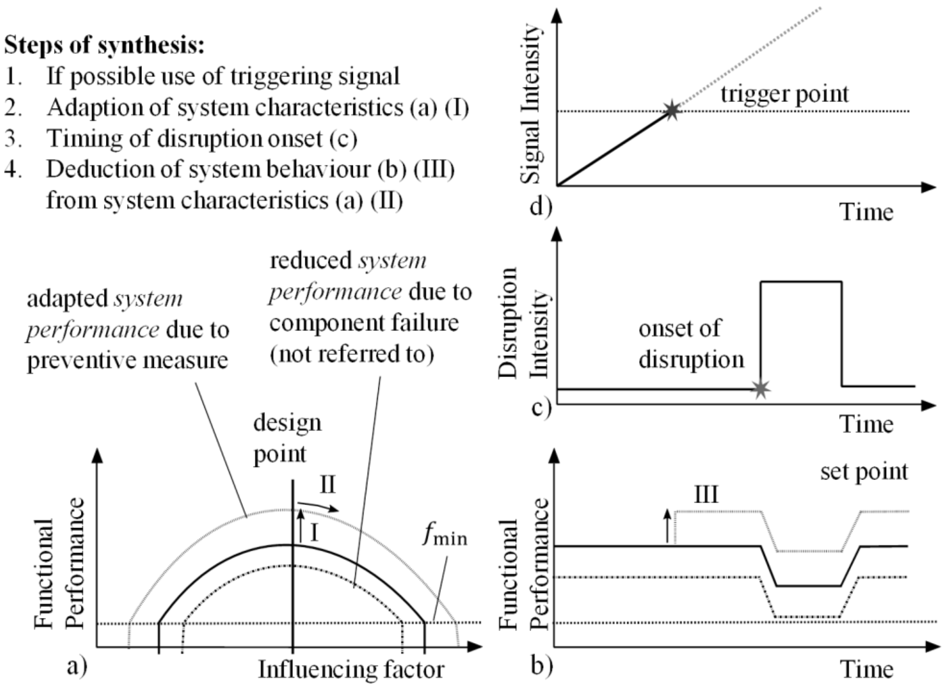

Figure 3: Resilience application model for designing resilient load-carrying systems

3 ADAPTIVITY

As stated above, the resilience characteristics and behaviour are basically achieved by the aspired and specified resilience functions. Realising these functions compels the ability of the system to *adapt* to changing environmental or system conditions.

Looking at natural organisms and engineered systems e.g., socioecological organisations, software systems or extended technical systems the resilient system properties are achieved by the high

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flexibility of such systems. In this case the system's *flexibility* ensures a high potential for *adaptivity*. In contrast to large and complex systems load-carrying systems and especially subsystems with limited expansion and complexity are characterised by a strongly restricted flexibility. The system's topology cannot be changed easily and damaged components cannot be replaced arbitrarily. Hence the main challenge of designing resilient load-carrying systems is to find solutions to adapt the system as required by the resilience functions. This adjustment is referred to as the system's *adaptivity* (Madni and Jackson, 2009).

Generally large complex systems are more flexible and able to easily restructure without external interference. This is mostly achieved by mechatronic components combined with an intelligent control or a human operator. (Jackson, 2016, Sun *et al.,* 2011) Less complex load-carrying systems, subsystems or even components in contrast necessitate new approaches to enable adaptivity. Because of their limited ability to change the building structure, *autonomous system reactions* as well as *externally induced system reactions* should be considered to realise the adaptivity in this case as distinguished in Table 1.

Adaptivity by autonomous system reactions of load-carrying systems mainly can be achieved by changing the load path in case of a disruptive event as a kind of improvisation. E.g., redundancy basically enables autonomous adaptivity by providing alternative load paths. Considering economy, functional redundancy is preferable to physical redundancy that requires additional components with the same functionality (also see the example of a run flat tyre in chapter 5). In contrast, functional redundancy is achieved by changing the load path to other components that are not primarily intended for this function. (Schlemmer *et al.*, 2018, Sun *et al.*, 2011)

Externally induced adaptivity usually requires the intervention of an operator. Because the intervention requires a certain time that depends on the amount and complexity of the adaption it has to be distinguished between *mid-* and *long-term adaptions*, like in Table 1, correlating to just *replacing* damaged components, exchanging them for (slightly) improved alternatives (*extended* capability) or convert to an *innovative* capability. (Schlemmer *et al.*, 2018)

4 SYNTHESIS OF RESILIENT LOAD-CARRYING SYSTEMS

As stated above, finding solutions to adapt the system as required by the resilience functions is the main challenge of designing resilient load-carrying systems. Thus providing design solutions is another key aid of the aspired design methodology. In the following a systematised structural framework for solution approaches is introduced which supports the step of finding a measure appropriate to realise resilience requirements for the system and its environment during the development process.

Looking at load-carrying systems the solution finding targets a fast reaction of the system or realisation of the adaption and a high efficiency according to the disruption. Therefore solutions and measures to realise resilience functions should be classified according to the systematics of adaptivity and time-dependent progress of disruptions:

- Short time disruption with complete decline of the disturbance, e.g. short impact of disturbance
- Continuing disruption at a constant level, e.g. component damage/basically changed application
- Steadily increasing disruption level, e.g. ongoing accumulation of load

Searching for suitable solutions to synthesise resilient load-carrying systems a lot of existing materials, products, design principles and measures are found to be capable of providing a minimum functionality in case of disruptions or even recover from damages; e.g., solutions based on the fail-safe principle.

The classification shown in Table 1 provides a systematically derived structured collection of solution approaches for developing resilient load-carrying systems. Solutions can be specifically selected according to the requirements derived from the resilience application model (Figure 3) and the shown solutions will be useful as a reference or at least for orientation. In Table 1 the following solutions are classified as an example.

1. Booster: short-term increase of the performance even in case of an overload; e.g. snow chains
2. Buffer: short-term compensation of disruption; e.g. emergency power supply
3. Redundancy: alternate load path; e.g. break system (hydraulic/electronic and mechanic)
4. Self-repairing components: e.g. self-sharpening blades (Rostek and Homberg, 2017)
5. Predetermined breaking point: System transferred to safe condition in case of overload; e.g. fuse
6. Self-repairing materials: e.g. Self-healing polymers and elastomers (Blaiszik *et al.*, 2010)
7. Shape memory alloys: e.g. actuator for switching valves at high temperatures

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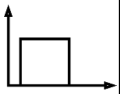
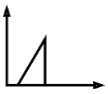
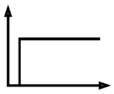
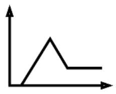
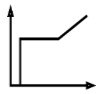
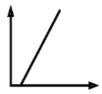
In Table 1 a small extract is shown to illustrate the underlying systematic approach and usability of the method. This solution catalogue can be successively extended and adapted to special applications.

Table 1: structural framework with embedded examples for solution approaches applicable for a certain combination of requirements and disruptions (italic numbers mean that the measure has a limited suitability and depends on additional measures)

System reaction	Timing of the measure	Disruption progress					
		complete decline of disruption		continuing constant disruption level		increasing disruption level	
		lasting 	non-lasting 	lasting 	non-lasting 	lasting 	non-lasting 
Autonomous (e. g. physical/ functional redundancy)	Proactive	3 (Redundancy)		3 (Redundancy)			
	Predictive	1 (Booster), 3		3 (Redundancy)			
	Active	1, 2, 3, 7 (Shape-memory-alloys)		3, 5		*3 (Redundancy)*	
	Reactive	1, 2, 3, 4, 6, 7		*2*, 3, 4, 6		*3, 6*	
Externally induced (e. g. replacement, extension, innovative extension)	Proactive	1, 2 (Buffer)		3 (Redundancy), 6			
	Predictive	1 (Booster), 2 (Buffer)		*6 (self-repairing materials)*			
	Active	1, 5, *2 (Buffer)*		*1*, 5, 6		5, *6*	
	Reactive	5 (predetermined breaking point)		4 (self-repairing components), 5, 6		5, *4*, *6*	

5 EXAMPLES

In the following two measures for coping with disruptions of tyres are introduced to illustrate resilience in load-carrying system. The examples cover the problems of pressure loss of tyres and adverse weather conditions considered as influencing factors.

5.1 Run flat tyre

A development to cope with pressure loss in tyres is the run flat tyre. The concept includes two variants shown in Figure 5. In one variant the sidewalls of the tyre are reinforced in the other a hard rubber structure is applied in the centre of the rim. Both enable the tyre to still offer enough carrying capacity to continue driving even in case of a complete pressure loss.

They can only be used in short-term and with reduced speed because the support structures are subject to a high level of wear and fatigue quickly. They also require a special rim to prevent a flat tyre from sliding off the rim. The run flat tyre can replace a spare wheel because it enables to continue driving despite a puncture to get to the next auto shop and change the tyre. This also offers the advantages of avoiding a change in an uncomfortable situation as well as a higher stability of the tyre and thus the car in a puncture situation which increases its safety. (Wiesinger, 2018, Bridgestone Americas Inc., 2018)

The run flat tyre deals with the disruption of pressure losses that occur in case of a puncture or collapse of the tyre which represents a subsystem failure. It uses the already known fail-safe principle. The disrupted system requires a countermeasure to maintain a minimum functionality. In this case the physically redundant reinforcement of the tyre respectively support structures on the rim offer additional support in case of the subsystem failure. The adaptivity of the run flat tyre ensues autonomously and applies temporary until the tyre is worn. Therefore the system uses the coping strategy responding. Consequently the system's answer to a disruption follows after its occurrence as a reactive measure. The measure just as the adaptivity ensues autonomously and only applies for short-term. The timing of the measure has two phases. The run flat tyre has to be integrated proactively to make it available in case of

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a disruption. The actual application then happens reactively to a disruption as the measure is triggered by the tyre breakdown. (Wiesinger, 2018, Bridgestone Americas Inc., 2018) Summarising the measure would be found in Table 1 under autonomous system reaction with a reactive timing and for a continuing constant and increasing disruption level. As a measure physical redundancy has been chosen whereby the italic number indicates that the measure is of limited sustainability for an increasing disruption level and additional measures like the exchange of the tyre are required.

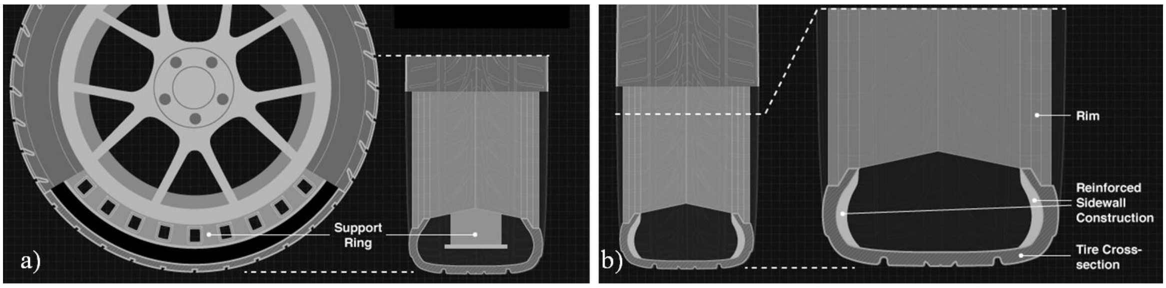

Figure 4: Run flat tyre with support structure (a) or reinforced sidewalls (b) (Bridgestone Americas Inc., 2018b, Bridgestone Americas Inc., 2018c)

The behaviour of the run flat tyre can be depicted in a resilience characteristics and resilience behaviour diagram. The tyre's performance is indicated by the traction and the roll resistance respectively the carrying capacity depending on the tyre pressure. (Wiesinger, 2018, Bridgestone Americas Inc., 2018)
Additional material for the reinforcement respectively the support of the tyre is needed to make the measure available. Apart from these previously provided one no resources are needed to apply the measure. Nonetheless integrating the reinforcement respectively support structure in combination with the required special rim cause additional effort and material and therefore costs. To further improve the resilience properties other solutions that are e.g. based on functional redundancy should be investigated. (Wiesinger, 2018, Bridgestone Americas Inc., 2018)

5.2 Rotogrip snow chains

Another opportunity to improve a car's resilience properties by influencing the tyres are snow chains. The snow chain system of Rotogrip enables to easily adapt to the road conditions. It consists of a snow chain gyroscope that can be activated by the driver in case of e.g. snow to be able to continue driving. The gyroscope swivels chains in the ground right in front the wheel to increase the road grip. As soon as the dangerous passage is over the snow chain gyroscope can be pulled up and kept under the car without affecting the driving behaviour of the car. (RUD Ketten Rieger & Dietz GmbH u. Co. KG, 2018)

Figure 5: Rotogrip snow chains (RUD Ketten Rieger & Dietz GmbH u. Co. KG, 2018b)

The snow chain gyroscope offers a measure for unpredictable operating conditions which in this case means disturbances due to mud, snowfall or black ice. The system adaptivity and thus the taken measure relies on the human operator assumed as the flexibility of the superior 'system'. It is also conceivable to autonomously control the system's use by the means of the detection of wheel spinning or a control system including a 'ground condition sensor'. The snow chain gyroscope can be used for short-term disturbances. It assumes the function of a booster as it increases the tyre's performance in case of a disturbance and while the installation of the gyroscope has to happen either *proactively* or *predictively* its application is performed *actively* by either a human or initiated *predictively* by a control system. The used resilience functions of this system are *monitoring* and *responding* as either a conceivable control system or the human operator detects the surrounding conditions and reacts accordingly. The human

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operator is also able to *anticipate* critical weather conditions prematurely and activate the snow chain gyroscope *predictively* on time. (RUD Ketten Rieger & Dietz GmbH u. Co. KG, 2018)
The snow chain gyroscope would be sorted into Table 1 under *autonomous* system reaction. The timing of the measure is active and it is applicable for completely declining disruptions. The resilience characteristics and behaviour of the snow chain gyroscope can be described similar to the properties of the run flat tyre. Traction and carrying capacity are plotted as a function of the road grip. The Rotogrip snow chain gyroscope requires additional components and resources in form of a control system, snow chains and a drive. This causes additional cost but on the other hand enables to handle environmental conditions that would cause a system breakdown i.e. a stuck car without the application of countermeasures. The snow chain gyroscope also offers a very short recovery time to chain free driving compared to conventional snow chains. (RUD Ketten Rieger & Dietz GmbH u. Co. KG, 2018)
The sorting in Table 1 strongly depends on the considered system boundary. Considering the tyre-road-system the gyroscope is referred to as *autonomous* while looking at the total car-system the gyroscope installation is referred to as *innovatively externally induced*.

6 CONCLUSION

Resilient systems have proven successful in nature and as socioecological systems as well as wide-spread networks because they are able to survive crisis and recover from damages. Transferring the resilience principle to load-carrying systems exceeds robust design and offers the opportunity to cope with or even control uncertainty caused by nescience during the system development. E.g., highly safety-relevant resilient load-carrying systems can be designed to guarantee a minimum functionality even in case of disruptions of any type.
Currently isolated solution approaches for resilient characteristics for load-carrying systems like fail-safe design already exist. However, a comprising methodology for the systematic development of resilient load-carrying systems is not available, yet. This publication contributes to such a development methodology by developing a resilience application model based on already defined resilience metrics and resilience functions. The resilience application model is usable for analysis and synthesis of resilient systems and comprises the interdependencies of the four aspects: static resilience characteristics, dynamic resilience behaviour, disruption progression and corresponding signal progression.
Furthermore, a systematically structured catalogue of solution approaches for resilient load-carrying systems was developed and is illustrated in chapter 4 as a small extract. This catalogue serves the developer as one solution finding method to synthesise resilient load-carrying systems. Additionally this catalogue offers the option to classify the measures according to the system context, the desired system properties and the occurrence of different disruption types.
Two examples point out the complexity of the design task but also illustrate the applicability of the solution catalogue and show the potential of the model for future development of design methods for the resilience analysis of reference systems, the planning of resilience properties and the development of resilient system structures. Moreover it is conceivable to formulate superordinate resilience strategies, principles and leverages to support the decision making while choosing appropriate solutions.
In detail, the development methodology is planned to cover the whole design process. It is supposed to start from the definition of requirements for resilient load-carrying systems depending on the appearance of the disruption with the help of the introduced metrics and the resilience application model. Knowing the requirements the systematic deduction of a suitable coping strategy with an underlying system structure shall be supported. Afterwards solution approached and design principles and guidelines can be chosen from the introduced classified measures. So far the support for the system deduction has to be developed.

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