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Systems Analysis for Assessing Cumulative Effects – a generic tool for all tiers

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1 Defining cumulative effects in the European and Swedish context of transport planning

There are currently many definitions of what constitutes a cumulative effect (CE). In 1999, the EU defined CEs in its guidance on the assessment of indirect and cumulative effects as the following:

> *"[Effects] that result from incremental changes caused by other past, present or reasonably foreseeable actions together with the project [and] the reactions between impacts whether between the impacts of just one project or between the impacts of other projects in the areas."*
> (Walker & Johnson, 2000, for the European Commission).

Notably, in the European context, CEs are considered to occur not only between different projects, but also within a project. At the same time, the term 'CE' still lacks an internationally accepted and universal definition (Blakley, 2021, pp. 5-8; Gunn & Noble, 2011; Noble, 2010; Wärnbäck & Hilding-Rydevik, 2009). Previous research has produced numerous different definitions of CEs, categorising different types of CEs. Looking at earlier research in the field, categories such as *linear additive effects, reinforcing or exponential effects, discontinuous effects* and *structural surprises* were identified. Most of these categories indicate that the outcome of the total effects caused by interactions within the system may be greater than the sum of the effects of individual processes (Duinker et al., 2013; Gunn et al., 2014; Gunn & Noble, 2011). Thus, a distinction is made between *additive effects, synergistic effects,* or *antagonistic effects*. More recent research has broadened the concept of CEs considerably. Blakley (2021, p. 6), for example, identified 40 different types of CEs in the environmental assessment literature.

A definition increasingly used in the scientific literature originates from the Canadian Council of Ministers of the Environment (e.g., Blakley & Russell, 2022). It states that a CE is

> *"a change in the environment caused by multiple interactions among human activities and natural processes that accumulate across time and space"*.
> (CCME, 2014).

Roudgarmi (2018) specifies that CEs cannot be understood, if they are limited to single projects, single steps in a project or to inappropriately small spatial or temporal scales. This means that all environmental effects in an environmental assessment have the potential to be CEs.

In the Swedish context, the assessment of CEs has been a requirement in environmental assessment legislation since 2004. However, it was not until 2018, when the amending directive was implemented in the Environmental Code (SFS 1998:808), that a somewhat clearer definition of CEs was added to Swedish practice. Further definitions appear in guidelines from different authorities. The Swedish Environmental Protection Agency (Naturvårdsverket, 2022) specifies CEs as *interacting, additive, synergistic* or *counteracting*. In the Swedish Transport Administration's latest guidance on environmental assessments, the types *interacting* and *counteracting* are applied (Trafikverket, 2022, p. 7). The Swedish Transport Administration's older guidelines use the categories *accumulative, interacting* or *additive direct* or *indirect effects* (Trafikverket, 2011).

To summarise, CEs arise from a very large number of interdependent factors within and between projects, which, taken as a whole, form a highly complex system and complicate any planning process. Each issue, however simple it may seem, can be linked to a very complex network of new problems, which in turn can neither be addressed nor solved from a single perspective.

2 Problems assessing cumulative effects

Previous research indicates a challenge with mandatory requirements as these can lead to practitioners perceiving the assessment of CEs as a mere necessity and thus underestimating the importance of assessing CEs. As a result, there is a risk that the necessary resources are not allocated to the assessment or that it is not integrated into the planning process (Sinclair et al., 2017).

This causes the assessment of CEs, should it at all be performed, to be included only as an additional chapter at the end of the EIA (Sinclair et al., 2017). In addition, Sinclair et al. (2017) point out that the complexity of the assessment of CEs, in combination with the lack of applicable resource-efficient and effective methods, discourages practitioners.

Previous research from Sweden shows that there are obstacles and difficulties among practitioners leading to CEs not being assessed to the degree they ought to be (e.g. Folkeson et al., 2013; Wärnbäck, 2007;

Wärnbäck & Hilding-Rydevik, 2009). In Wärnbäck's (2007) study, the practitioners stated that they had little or no knowledge of the concept of CEs or the requirements for CEs. Furthermore, they had little or no knowledge of how to go about assessing CEs.

There is a consensus in the international literature that the need to improve the process of assessing CEs is of utmost urgency (Duinker et al., 2013; Gunn et al., 2014; Noble, 2010). In a review of the international literature on CEs in environmental assessments, Folkeson et al. (2013) point out that there is a large gap between practice and science-based approaches, resulting in a lack of methods for assessing CEs in practice.

Previous international research on environmental assessments indicates that a systems perspective, i.e., systems thinking and systems analysis, can contribute to increasing the effectiveness of environmental assessments (e.g. Partidário, 2021; Pope et al., 2018). Furthermore, several studies that have evaluated environmental assessments conclude that it is the actual execution of environmental assessments that is one of the most important factors for the successful integration of sustainability, i.e. the substantive effectiveness (Balfors et al., 2018; Chanchitpricha & Bond, 2013; Kørnøv et al., 2011).

Various proposals for procedures and frameworks for dealing with CEs in environmental assessments have been developed in Sweden (Folkeson, 2010; Malmaeus et al., 2022; Naturvårdsverket, 2022), clearly illustrating the need to integrate the assessment of CEs throughout various tiers.

3 Complexity and systems

With a growing understanding of CEs and related complexity of interacting anthropological and environmental systems, the need for time and cost effective methods and tools to map, analyse and communicate the nature of CE with a holistic or systematic approach, or systems thinking, is increasingly emphasised in scientific literature (e.g. Grace & Pope, 2021; Gunn et al., 2014; Hodgson & Halpern, 2019; Hodgson et al., 2019; Partidário, 2021).

Complexity arises as a result of interactions between a certain number of variables, constituting a system that behaves in a certain way due to its structure (e.g. Sterman, 2000). The outcome of the interactions within a complex system is often non-linear due to various feedback mechanisms (e.g. Sterman, 2000). A non-linear trend (i.e., exponential growth or decline) may be small or insignificant at first and then increase rapidly (e.g.

Sterman, 2000). This means that if the assessment of a system is too short-term, major effects of the project may be missed and subsequently perceived as surprises. Complex systems are very difficult to delineate as they are strongly interconnected with their surroundings. In a planning context, this means that each environmental aspect constitutes a complex system in itself. When aspects are linked together, complexity increases and further links to the surrounding environments are added. These can be physical, social, political or of any other nature.

Systems thinking is a way of looking at different complex contexts in relation to a problem as well as the very process of understanding complex systems (e.g. Forrester, 1985; Kopainsky et al., 2015; Sterman, 2000). Arnold and Wade (2015), after comparing and analysing different definitions, formulated systems thinking as

"a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects."
(Arnold & Wade, 2015)

System analysis originated in economic theory (Forrester, 1985) and was further developed by, for example, Meadows et al. (2006) and the Club of Rome. The methodology is increasingly applied in environmental science to understand dynamic complexity and non-linear behaviour and change over time and space. The method follows a series of steps to identify the variables that make up a system and how they are linked through causal relationships. These give rise to the structure of the system and thus its behaviour, expressed as different types of effects (e.g. Sterman, 2000).

There is an upper limit to the human ability to process information about simultaneously interacting elements and non-linear behaviour (Miller, 1956). Much research has been conducted since, contributing to applied systems analysis being based on simplifying reality in the form of maps called causal loop diagrams (CLDs) (Bureš, 2017, Sterman, 2000). In order to deal with complexity in a reasonable way, simplified versions of the system are created in the form of aggregated qualitative CLDs (Bureš, 2017).

4 Systems analysis for the assessment of CE in transport planning

When planning large **transport infrastructures**, especially in environments with high natural, cultural or social values, many different aspects are affected, that are inherently strongly connected in different ways (Kelly (Letcher) et al., 2013). We argue that different effect pathways from different directions create a **CE** in the recipient, i.e., variable A is affected by B and C simultaneously. CEs can also be described as multi-input (MI) variables. MI variables may also have multiple outputs (MO), which, when combined, form the structure and resulting behaviour of the system (Bureš, 2017). Through these linkages, effects arising at one point can spread through different pathways and lead to effects at other locations in the system, i.e., at various other environmental aspects (Figure 1).

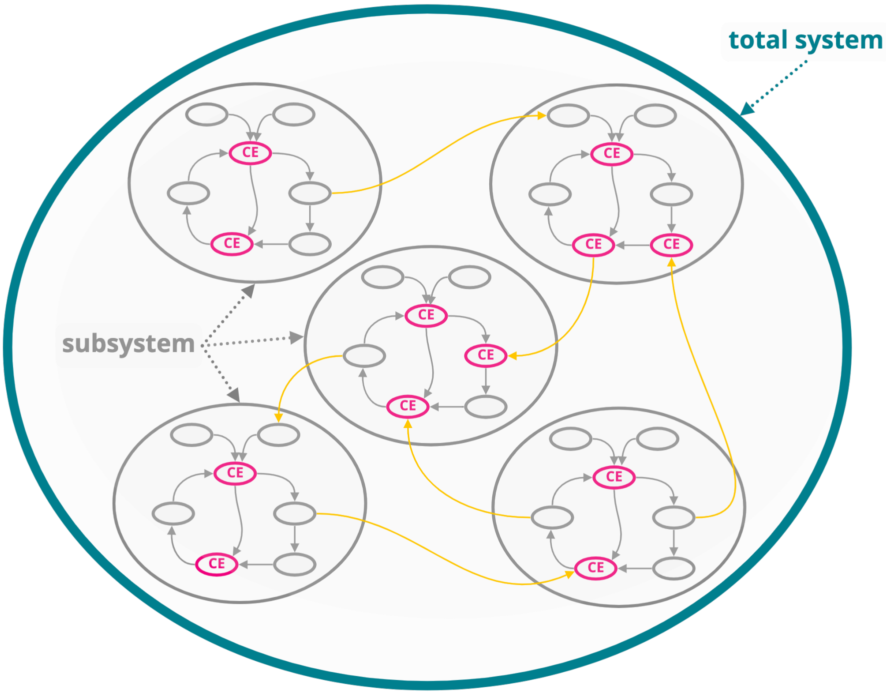

Figure 1. A schematic illustration of subsystems representing an environmental aspect (grey) and consisting of different variables. The variables are linked to other variables through causal relationships, some of which also link the different aspects to each other (yellow arrows). In variables that are recipients of several effects, a cumulative effect occurs. The totality of all interconnected subsystems forms a total system (blue).

Resulting effects can be linear, i.e., pathways go from A to C via B and lead to an increasing or decreasing effect, or they can create feedbacks as they move from A via B back to A, giving rise to non-linear reinforcing or balancing effects. Reinforcing feedbacks can drive a system to overshoot and collapse, when tipping points are exceeded. Balancing feedbacks can counteract reinforcements, creating a state of equilibrium. The equilibrium may be disrupted when the system is exposed to disturbances or exogenous driving forces such as the impacts of a road or railway project or climate change. Natural systems always strive to return to equilibrium. However, a new equilibrium in a disturbed system may be at a different level than before and thus lead to undesired short or long-term effects (Sterman, 2000).

Systems analysis enables the understanding of system structure and behaviour. This means, that leverage points, i.e., places in the system, where a structural change can counteract undesired short or long-term effects, can be identified. In practice, a holistic understanding of the system allows for targeted and effective mitigation or adaptations measures (Sterman, 2000).

The iterative modelling process crystallises not only relevant variables, linkages and specific connection points between the variables and the subsystems, but also enables clear delineation between the subsystems (Sterman, 2000). A clear delimitation reduces the risk of repetition and strong overlaps between the descriptions of the environmental aspects which can promote more effective co-operation between subject areas.

Further, CLDs can support communication between subject areas by creating a common language and way of thinking as well as a mutual understanding and insight into different subject areas (e.g. Perrone et al., 2020; Vennix, 1995). The experts' individual way of seeing and describing the individual subject areas based on their own work tradition and their own specialised language and methodology could be a barrier. For project management, the sub-models and the overall model can support planning, coordination, and communication through all tiers.

The common process and approach of environmental assessment has many similarities with systems thinking and analysis, such as the flow-oriented procedure with clear procedural requirements and assessment of environmental aspects. We therefore argue that a qualitative system analysis in combination with the knowledge and skills of practitioners is most likely sufficient to assess CEs effectively.

References

Arnold, R. D., & Wade, J. P. (2015). A Definition of Systems Thinking: A Systems Approach. *2015 Conference on Systems Engineering Research*, *44*, 669-678.

Balfors, B., Antonson, H., Faith-Ell, C., Finnveden, G., Gunnarsson-Östling, U., Hörnberg, C., Isaksson, K., Lundberg, K., Pädam, S., & Söderqvist, T. (2018). *Strategisk miljöbedömning för hållbar samhällsplanering: Slutrapport från forskningsprogrammet SPEAK*.

Blakley, J., & Russell, J. (2022). International progress in cumulative effects assessment: a review of academic literature 2008–2018. *Journal of Environmental Planning and Management*, *65*(2), 186-215.

Blakley, J. A. E. (2021). Foundations, issues and contemporary challenges in cumulative impact assessment. In J. A. E. Blakley & D. M. Franks (Eds.), *Handbook of Cumulative Impact Assessment* (pp. 416). Edward Elgar Publishing Limited.

Bureš, V. (2017). A Method for Simplification of Complex Group Causal Loop Diagrams Based on Endogenisation, Encapsulation and Order-Oriented Reduction [Article]. *Systems*, *5*(3), 46.

CCME. (2014). *Canada-wide Definitions and Principles for Cumulative Effects* Winnipeg, MB

Chanchitpricha, C., & Bond, A. (2013). Conceptualising the effectiveness of impact assessment processes. *Environmental Impact Assessment Review*, *43*(65-72).

Duinker, P. N., Burbidge, E. L., Boardley, S. R., & Greig, L. A. (2013). Scientific dimensions of cumulative effects assessment: toward improvements in guidance for practice. *Environmental Reviews*, *21*(1), 40-52.

Folkeson, L. (2010). *Kumulativa effekter och konsekvenser: behandling i miljöbedömning och miljökonsekvensbeskrivning för vägar* (VTI rapport, Issue. S. v.-o. t. (Sweden).

Folkeson, L., Antonson, H., & Helldin, J. O. (2013). Planners' views on cumulative effects. A focus-group study concerning transport infrastructure planning in Sweden. *Land Use Policy*, *30*(1), 243-253.

Forrester, J. W. (1985). "The" model versus a modeling "process". *System Dynamics Review*, *1*(1), 133-134.

Grace, B., & Pope, J. (2021). A systems approach to cumulative social impact assessment. In J. A. E. Blakley & D. M. Franks (Eds.), *Handbook of Cumulative Impact Assessment* (pp. 416). Edward Elgar Publishing Limited.

Gunn, A., Russell, D., & Greig, L. (2014). Insights into integrating cumulative effects and collaborative co-management for migratory tundra caribou herds in the Northwest Territories, Canada. *Ecology and Society*, *19*(4), 1-18.

Gunn, J., & Noble, B. F. (2011). Conceptual and methodological challenges to integrating SEA and cumulative effects assessment. *Environmental Impact Assessment Review*, *31*(2), 154-160.

Hodgson, E. E., & Halpern, B. S. (2019). Investigating cumulative effects across ecological scales. *Conserv Biol*, *33*(1), 22-32.

Hodgson, E. E., Halpern, B. S., & Essington, T. E. (2019). Moving Beyond Silos in Cumulative Effects Assessment. *Frontiers in Ecology and Evolution*, *7*(JUN), 1-8, Article 211.

Kelly (Letcher), R. A., Jakeman, A. J., Barreteau, O., Borsuk, M. E., Elsawah, S., Hamilton, S. H., Henriksen, H. J., Kuikka, S., Maier, H. R., Rizzoli, A. E., Van Delden, H., & Voinov, A. A. (2013). Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling & Software*, *47*, 159-181.

Kopainsky, B., Alessi, S. M., & Davidsen, P. I. (2015). Measuring Knowledge Acquisition in Dynamic Deci- sion Making Tasks Introduction and background. *The 29th International Conference of the System Dynamics Society*(July 2011), 1-31.

Kørnøv, L., Lyhne, I., Vannem-Larsen, S., & Merrild-Hansen, A. (2011). Change Agents in the Field of Strategic Environmental Assessment: What Does it Involve and What Potentials Does it Have for Research and Practice? *Journal of Environmental Assessment Policy and Management*, *13*(2), 203-228.

Malmaeus, M., Hellsten, S., & Lindblom, E. (2022). *Miljöbedömning av kumulativa effekter i infrastrukturprojekt*.

Meadows, D., Randers, J., & Meadows, D. (2006). *Limits to Growth: The 30-Year Update* (Vol. 22). Earthscan.

Naturvårdsverket. (2022). *Kumulativa effekter inom specifik miljöbedömning*. Retrieved 17 januari from

Noble, B. (2010). Cumulative Environmental Effects and the Tyranny of Small Decisions: Towards Meaningful Cumulative Effects Assessment and Management. *Natural Resources and Environmental Studies Institute Occasional Paper No. 8*(8).

Partidário, M. R. (2021). Handbook on Strategic Environmental Assessment. In T. B. Fischer & A. González (Eds.), *Handbook on Strategic Environmental Assessment* (pp. 41–57). Edward Elgar Publishing.

Perrone, A., Inam, A., Albano, R., Adamowski, J., & Sole, A. (2020). A participatory system dynamics modeling approach to facilitate collaborative flood risk management: A case study in the Bradano River (Italy). *Journal of Hydrology*, *580*.

Pope, J., Bond, A., Cameron, C., Retief, F., & Morrison-Saunders, A. (2018). Are current effectiveness criteria fit for purpose? Using a controversial strategic assessment as a test case. *Environmental Impact Assessment Review*, *70*, 34-44.

Roudgarmi, P. (2018). Cumulative Effects Assessment (CEA), A Review. *Journal of Environmental Assessment Policy and Management*, *20*, 1850008.

SFS 1998:808. *Miljöbalk*.

Sinclair, A. J., Doelle, M., & Duinker, P. N. (2017). Looking up, down, and sideways: Reconceiving cumulative effects assessment as a mindset. *Environmental Impact Assessment Review*, *62*, 183-194.

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. McGraw-Hill Education.

Trafikverket. (2011). *Miljökonsekvensbeskrivning för vägar och järnvägar: Handbok, Metodik* (2011:090).

Trafikverket. (2022). *Miljöbedömning och miljöbeskrivning i väg- och järnvägs projekt - Vägledning* (2022:100).

Vennix, J. a. M. (1995). Building consensus in strategic decision making: System dynamics as a group support system. *Group Decision and Negotiation*, *4*(4), 335-355.

Walker, L. J., & Johnson, J. (2000). Assessment of indirect and cumulative impacts as well as impact interactions. In f. t. E. Commission (Ed.), (Vol. 3). Luxembourg: EC DG XI Environment, Nuclear Safety & Civil Protection.

Wärnbäck, A. (2007). *Cumulative effects in Swedish impact assessment practice* [Licentiate, SLU]. Uppsala.

Wärnbäck, A., & Hilding-Rydevik, T. (2009). Cumulative effects in Swedish EIA practice - difficulties and obstacles. *Environmental Impact Assessment Review*, *29*(2), 107-115.