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Matthew C. Davis, Helen P. N. Hughes, Alison McKay, Mark A. Robinson & C. Natalie van der Wal. *Ergonomists as designers: computational modelling and simulation of complex socio-technical systems*. Pages: 938-951.

Contemporary ergonomics problems are increasing in scale, ambition, and complexity. Understanding and creating solutions for these multi-faceted, dynamic, and systemic problems challenges traditional methods. Computational modelling approaches can help address this methodological shortfall. We illustrate this potential by describing applications of computational modelling to: (1) teamworking within a multi-team engineering environment; (2) crowd behaviour in different transport terminals; and (3) performance of engineering supply chains. Our examples highlight the benefits and challenges for multi-disciplinary approaches to computational modelling, demonstrating the need for socio-technical design principles. Our experience highlights opportunities for ergonomists as designers and users of computational models, and the instrumental role that ergonomics can play in developing and enhancing complex socio-technical systems. Recognising the challenges inherent in designing computational models, we reflect on practical issues and lessons learned so that computational modelling and simulation can become a standard and valuable technique in the ergonomists' toolkit. **Practitioner summary:** This paper argues that computational modelling and simulation is currently underutilised in ergonomics research and practice. Through example applications illustrating the benefits, limitations, and opportunities of such approaches, this paper is a point of reference for researchers and practitioners using computational modelling to explore complex socio-technical systems.

- **Keywords:** Modelling and simulation, agent-based modelling, socio-technical systems, complex systems

Mashal Farid, Nancy Purdy & W. Patrick Neumann. *Using system dynamics modelling to show the effect of nurse workload on nurses' health and quality of care*. Pages: 952-964.

The objective of the current study is to explore System Dynamics modelling to quantify and understand the effects of nursing workload on nurse burnout, absenteeism, and

quality of patient care. A literature search was performed to identify the causal relationships between factors related to the problem and build a conceptual causal loop diagram. Each of these factors was then operationalised and a simulation model was built using quantitative empirical data from the literature, supplemented with expert input. The model results showed that long nurse shifts and work weeks double nurse fatigue levels, while increasing burnout by up to 6 times, absenteeism by up to 5 times, and medical errors for the patients increasing by up to 150%. The study demonstrates a novel application of System Dynamics in healthcare to examine the impact of management strategies and healthcare system design on nurses' wellbeing and on care quality. **Practitioner summary:** System Dynamics Modelling allows for the integration of available scientific evidence and expertise to reveal the relationship between nurse workload, burnout and care quality in terms of medical errors. Such models can reveal possible responses from proposed policy or system design changes that could not be quantified with conventional approaches.

- **Keywords:** Simulation, healthcare ergonomics, psychosocial factors, human factors, sociotechnical systems, macroergonomics

Paul M. Salmon, Gemma J. M. Read, Jason Thompson, Scott McLean & Rod McClure. *Computational modelling and systems ergonomics: a system dynamics model of drink driving-related trauma prevention*. Pages: 965-980.

System dynamics is a computational modelling method that is used to understand the dynamic interactions influencing behaviour in complex systems. In this article we argue that the method provides a useful tool for ergonomists wishing to model the behaviour of complex systems. We present a system dynamics model that simulates the behaviour of a drink driving-related trauma system and explore the potential impact of different road safety policy interventions. The model was simulated over thirty-year periods with different policy interventions. The findings suggest that the greatest reduction in drink driving-related trauma can be achieved by policies that integrate standard road safety interventions (e.g. education and enforcement) with interventions designed to address the societal issue of alcohol misuse and addiction. In closing we discuss the potential use of system dynamics modelling in future ergonomics applications and outline its strengths and weaknesses in relation to existing systems ergonomics methods. **Practitioner Summary:** The outputs of systems ergonomics methods are typically static and cannot simulate behaviour over time. We propose system dynamics as a useful approach for modelling the behaviour of complex systems. Applied to drink driving-related road trauma, the method was able to dynamically model the potential impacts of different policy interventions.

- **Keywords:** System dynamics, drink driving, road safety, systems ergonomics, computational modelling

Jason Thompson, Gemma J. M. Read, Jasper S. Wijnands & Paul M. Salmon. *The perils of perfect performance; considering the effects of introducing autonomous vehicles on rates of car vs cyclist conflict*. Pages: 981-996.

How humans will adapt and respond to the introduction of autonomous vehicles (AVs) is uncertain. This study used an agent-based model to explore how AVs, human-operated vehicles, and cyclists might interact based on the introduction of flawlessly performing AVs. Under two separate experimental conditions, results of experiment 1 showed that, despite no conflicts occurring between cyclists and AVs, modelled conflicts among human-operated cars and cyclists increased with the introduction of AVs due to cyclists' adjusted expectations of the behaviour and capability of human-operated and

autonomous cars. Similarly, when human-operated cars were replaced with AVs over time in experiment 2, cyclist conflict rates did not follow a linear reduction consistent with the replacement rate but decreased more slowly in the early stages of replacement before 50% substitution. It is concluded that, although flawlessly performing AVs might reduce total conflicts, the introduction of AVs into a transport system where humans adjust to the behaviour and risk presented by AVs could create new sources of error that offset some of AVs assumed safety benefits. **Practitioner summary:** Ergonomics is an applied science that studies interactions between humans and other elements of a system, including non-human agents. Agent-Based Modelling (ABM) provides an approach for exploring dynamic and emergent interactions between agents. In this article, we demonstrate ABM through an analysis of how cyclists and pedestrians might interact with Autonomous Vehicles (AVs) in future road transport systems.

- **Keywords:** Cycling, safety, traffic, health, autonomous vehicles, agent-based modelling

Patrycja Antosz, Tomasz Rembiasz & Harko Verhagen. *Employee shirking and overworking: modelling the unintended consequences of work organisation*. Pages: 997-1009.

Underworking (i.e. shirking) and overworking of employees can have detrimental effects for the individual and the organisation. We develop a computational model to investigate how work structure, specifically the way in which managers distribute work tasks amongst employees, impacts work intensity and working time. The model draws on theories from economics, psychology and management, and on empirical observations. The simulations show that when managers correctly estimate task difficulty, but undervalue the employee's competence, opportunities for shirking are provided due to longer deadlines. Similarly, if managers overvalue the employee's competence, they set tighter deadlines leading to overwork. If task difficulty is misjudged, initially only influence on employee working time is observed. However, it gradually generates competence misjudgements, indirectly impacting the employee's effort level. An interaction between competence misjudgement and task uncertainty slows the manager's ability to correctly estimate employee competence and prolongs initial competence misjudgements. The study highlights the importance of applying dynamic modelling methods, which allows for testing theory assumptions *in silico*, generating new hypotheses and offers a foundation for future research. **Practitioner summary:** A computational model was developed to investigate how the structure of work allocation influences opportunities for shirking and overworking by employees. The paper demonstrates how dynamic modelling can be used to explain workplace phenomena and develop new hypotheses for further research.

- **Keywords:** Task performance, shirking, agent-based model, social simulations

Hamed Asadi, Guoyang Zhou, Jae Joong Lee, Vaneet Aggarwal & Denny Yu. *A computer vision approach for classifying isometric grip force exertion levels*. Pages: 1010-1026.

Exposure to high and/or repetitive force exertions can lead to musculoskeletal injuries. However, measuring worker force exertion levels is challenging, and existing techniques can be intrusive, interfere with human–machine interface, and/or limited by subjectivity. In this work, computer vision techniques are developed to detect isometric grip exertions using facial videos and wearable photoplethysmogram. Eighteen participants (19–24 years) performed isometric grip exertions at varying levels of maximum voluntary contraction. Novel features that predict forces were identified and extracted from video and photoplethysmogram data. Two experiments with two (High/Low) and three (0%MVC/50%MVC/100%MVC) labels were performed to classify exertions. The Deep Neural Network classifier performed the best with 96% and 87% accuracy for two- and

three-level classifications, respectively. This approach was robust to leave subjects out during cross-validation (86% accuracy when 3-subjects were left out) and robust to noise (i.e. 89% accuracy for correctly classifying talking activities as low force exertions). **Practitioner summary**: Forceful exertions are contributing factors to musculoskeletal injuries, yet it remains difficult to measure in work environments. This paper presents an approach to estimate force exertion levels, which is less distracting to workers, easier to implement by practitioners, and could potentially be used in a wide variety of workplaces.

- **Keywords:** Computer vision, high force exertions, facial expressions, machine learning

David Golightly, Carl Gamble, Roberto Palacin & Ken Pierce. *Applying ergonomics within the multi-modelling paradigm with an example from multiple UAV control*. Pages: 1027-1043.

This article presents a position statement on using ergonomics in conjunction with the multi-modelling paradigm. Multi-modelling is a computational approach to combine models of systems and components for design and simulation of cyber physical systems and systems of systems. Despite potentially significant benefits in terms of more human-centric system modelling, there is limited evidence of the application of ergonomics within multi-modelling. This article presents the case for applying ergonomics within multi-modelling. We open with an introduction to multi-modelling and benefits, applications and gaps for ergonomics in multi-modelling, and of potentially useful models from ergonomics. We then describe a proof-of-concept implementation of ergonomics within a multi-model of UAV control. This demonstrates that as well as user-centred modelling, this approach supports ergonomics in how we can access rich systems models, and the collaborative value of applying ergonomics theory in systems design. **Practitioner Summary:** Examines multi-modelling, a computational approach for complex modelling, and the contribution of ergonomics. An autonomous UAV test implementation demonstrates the application of ergonomics knowledge for improving design and evaluation processes, and how multi-modelling can give ergonomics access to rich systems models.

- **Keywords:** Computational modelling, UAV, control systems, automation, cyber-physical systems

Mohammed Ibrahim Shire, Gyuchan Thomas Jun & Stewart Robinson. *Healthcare workers' perspectives on participatory system dynamics modelling and simulation: designing safe and efficient hospital pharmacy dispensing systems together*. Pages: 1044-1056.

With increasingly complex safety-critical systems like healthcare being developed and managed, there is a need for a tool that permits decision-makers to better understand the complexity, test various strategies and guide effective changes. System Dynamics (SD) modelling is an effective approach that can aid strategic decision-making in healthcare systems but has been underutilised partly due to the challenge of engaging healthcare stakeholders in the modelling process. This paper, therefore, investigates the applicability of a participatory SD approach based on healthcare workers' perspectives on ease of use (usability) and usefulness (utility). The study developed an interactive simulation dashboard platform which facilitated participatory simulation for exploring various hospital pharmacy staffing level arrangements and their impacts on interruptions, fatigue, workload, rework, productivity and safety. The findings reveal that participatory SD approach can enhance team learning by converging on a shared mental model, aid decision-making and identifying trade-offs. The implications of these findings are discussed as well as experience and lessons learned on modelling facilitation. **Practitioner Summary:** This paper reports the perspectives of healthcare workers, who

were engaged with a participatory system dynamics modelling and simulation process for hospital pharmacy staffing level management. Evaluative feedback revealed that the participatory SD approach can be a valuable tool for participatory ergonomics by helping the participants gain a deeper understanding of the complex dynamic interactions between workload, rework, safety and efficiency.

- **Keywords:** Participatory modelling, computer simulation, pharmacy dispensary, healthcare, group-model-building

Matt Holman, Guy Walker, Terry Lansdown & Adam Hulme. *Radical systems thinking and the future role of computational modelling in ergonomics: an exploration of agent-based modelling*. Pages: 1057-1074.

We are teetering on the precipice of the imminent Fourth Industrial Revolution. In this new age, systems are set to become more densely intraconnected and interconnected, and massive sociotechnical systems exhibiting unprecedented levels of complexity will increasingly take hold. At the dawning of this new age, the Ergonomics discipline must reflect on its preparedness for tackling problems in these novel systems. This paper engages in this reflection by putting forth a critical commentary on the implication of these changes on the discipline and discusses the utility of our current methods in this new paradigm. A resulting Radical Systems Thinking in Ergonomics Manifesto is put forward – a set of mandates to guide practitioners and researchers in the development of new methods capable of coping with these imminent challenges. From the manifesto are derived a series of capability requirements for future computational modelling approaches in Ergonomics. **Practitioner summary:** The goal of this paper was to inspire the Ergonomics community to pursue further applications involving computational modelling approaches such as Agent-Based Modelling. It presents a manifesto for the future of the discipline, and from this the capabilities that future computational modelling approaches need to possess.

- **Keywords:** Ergonomics, computational modelling, systems thinking, AI, IoT