Forest operations engineering and management – the ways behind and ahead of a scientific discipline

Hans Rudolf Heinimann

Abstract – Nacrtak

The forest operations engineering and management community has been facing the problem of improving its scientific visibility, realigning its research efforts to the future challenges, and of strengthening its self-confidence. The paper aims at exploring the paradigms that shaped the development of forest operations as a scientific discipline, sketching a vision how forest operations could look like in 2020, establishing a common understanding for future of the discipline, and discussing the major challenges ahead. The investigation identified five periods of steady state development (paradigms) and developed a vision of network-based forest operations systems, built of »self-organizing« cells. It then discusses the challenges that we will probably been faced with in the fields of »harvesting and transportation engineering«, »forest operations management«, »forest ergonomics«, and »forest operations ecology«. The study intended to trigger a broad discussion on the future directions of forest operations engineering and management, and to build a basis for a redesign of corresponding curricula in higher education.

Keywords: forest operations, forest engineering, paradigms, future challenges, scientific discipline, historical development

1. Introduction – *Uvod*

Forest operations has been the prevailing term to characterize a scientific discipline, which addresses design, implementation, control, and continuous improvement of forest operations systems. The value of a problem-oriented discipline depends on its recognition within the family of scientific communities, and on its capability to provide solutions to emerging problems. In the last 10 years, we have been facing fundamental economic, social and environmental changes that can be characterized by trends, see for example (Davis and Stephenson 2006). Forest operations as technology-based discipline is both technology, and problem driven. Information, WWW, and sensor technology have had a big influence on our field of interest. On the other hand, the problems of global change, increasing demand for resources, or the critical attitude of society towards technology have been shaping the development as well. In our point of view, the voice of the forest operations community has been weak or has even fallen silent, resulting in decreasing funding and recognition. The International Union of Forest Research Organization IUFRO has undertaken a major effort (1) to strengthen research, (2) to expand strategic partnership and cooperation, (3) to enhance the commutation with the scientific community, and (4) to improve the commutation with policy makers. Such a development should be driven by future challenges, and be based on a common understanding what the fundamentals of the corresponding scientific discipline are. Previous papers on forest operations as a scientific discipline covered the periods from the 1970s to the 1990s (Heinimann 1995, Samset 1992, Sundberg 1988).

The present paper aims at (1) exploring the conceptual worldviews (paradigms) that shaped the development of forest operations as a scientific discipline, (2) sketching a vision how forest operations could look like in 2020, (3) establishing a common understanding for the future of our discipline, and (4) discussing the major challenges that we will probably been faced with. The scope of the paper is somewhat limited by the perceptions, expectations and values of the author, which will influence the ideas on future developments. It is also shaped by the »western« perspective that probably neglects to developments in other cultural areas. The paper will first describe five paradigmatic phases of development, next sketch a 2020 vision of forest operations system as network-systems of self-organized cells, then proposes a definition of forest operations engineering and management as a scientific discipline, and finally sketch the challenges for harvesting and transportation engineering, forest operations management, forest ergonomics, and forest operations ecology.

2. The Way Behind – *Osvrt unazad*

2.1 The Phenomenon of Discontinuous Evolution – *Fenomen diskontinuirane evolucije*

Scientific disciplines have been continuously evolving, similar to biological systems. Understanding possible paths of future development requires a basic understanding of how systems change over time. In biology, evolution has been understood as a »slow stream of mutations«, that gradually results in novel forms of organisms and systems (Gersick 1991). However, a new theory of »discontinuous evolution« has been challenging the concept of continuous, gradual change (Gould and Eldredge 1993). It is based on the assumption that systems exist for most of their history in a series of consecutive, steady state levels that are connected by sudden, non-linear »punctuations« of discontinuous change. Relatively long periods of stability are punctuated by compact periods of qualitative, metamorphic changes. This concept of punctuated equilibrium can be found in several areas of science, e.g. in biology (Gould and Eldredge 1993), in philosophy of science (Kuhn 1970), organizational theory (Gersick 1991), or software development (Aoyama 2002, Wu et al. 2004).

Thomas Kuhn (Kuhn 1970) accordingly provided a model of »punctuated equilibrium« for scientific disciplines, for which he called steady state periods as »normal science«, and periods of discontinuous change as »scientific revolutions«. He introduced the term »paradigm« to characterize a specific steady state period of »normal science«. Ivar Samset, one of the leading forest operations scholars of the 1950s and 1960s was the first to describe the phenomenon of »discontinuous evolution« related to forest operations (Samset 1966). Although he did not identify patterns of discontinuous evolution for our scientific discipline as a whole, he presented findings for punctuated discontinuity for the evolution of Norwegian cable systems. Previous studies of the author (Heinimann 1995, Heinimann 1997) indicated that similar evolutionary patterns may be found for the whole domain of forest operations engineering and management. However, we are far away from fully understanding the emergence and the development of our field of interest, because there is not only variation in time but also variation in space that results in different paths of development in different areas of the world.

2.2 Paradigmatic Patterns of Evolution – *Paradigmatski uzorci evolucije*

Following Kuhn (Kuhn 1970), paradigms are conceptual world-views that (1) define scientific thought (basic assumptions), (2) determine the problems to be important, and (3) shape the type of questions to be investigated. Paradigm shifts (1) alter the fundamental concepts underlying research, (2) inspire new pathways of theory and experiment, (3) encourage new research techniques, and (4) promote new standards of evidence. The question to be asked is if those alternating patterns of relative stability and drastic changes can be observed in our field of interest, forest operations engineering and management, as well.

Our investigation is based on the assumption that the »big picture« of evolution of forest operations engineering and management may be characterized by two main dimensions: (1) scientific theories and procedures (x-axis in Fig. 1), and (2) the observed and scrutinized level of complexity of the study objects (y-axis in Fig. 1). The level of complexity follows the »skeleton of science« as proposed by Boulding (Boulding 1956).The first dimension, scientific theories and procedures, can be described by a consecutive sequence of scientific procedures. The second dimension, the level of complexity, by a distinct set of complexitiy levels, ranging from a simple, static framework to self-adapting, autonomous systems (Fig. 1).

The five steady state periods of evolution (Fig. 1) will below be described in more detail.

2.2.1 Utilization paradigm – *Paradigma korištenja*

The emergence of organized records of forest operations knowledge goes back to the 17th century when engineering knowledge was recorded systematically by proponents of mercantilism in France. The textbooks published by Duhamel du Monceau, a high-ranked French civil-servant, is – according to our knowledge – the cradle of forest operations engineering and management in the modern scientific world. The first title of a trilogy, »The art of making

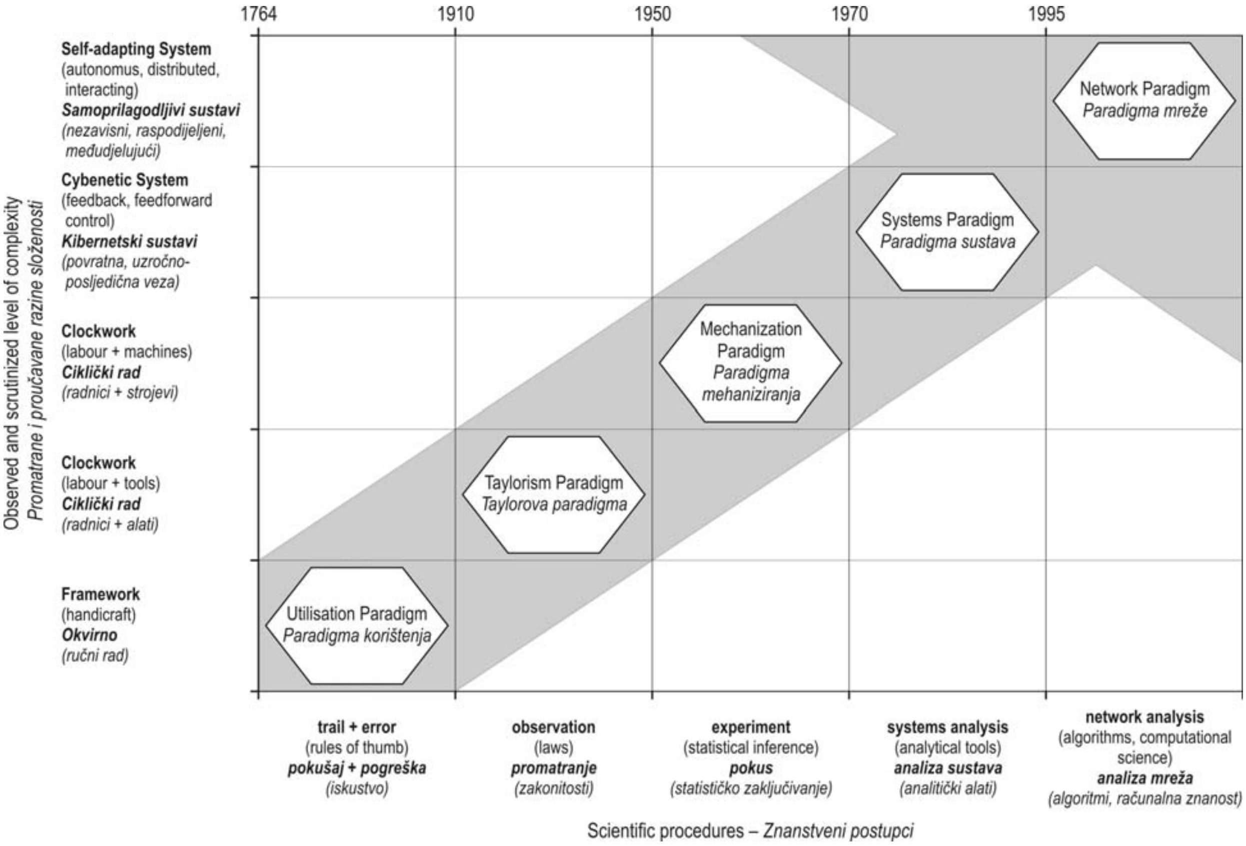

Fig. 1 Patterns of evolution characterizing the evolution forest operations engineering and management as a scientific discipline
Slika 1. *Uzorci evolucije koji opisuju evoluciju šumarskoga inženjerstva i upravljanja šumskim radovima kao znanstvenu disciplinu*

charcoal« (Duhamel du Monceau 1761), was followed by »Forest utilization – with a description of the art of forest practices« (Duhamel du Monceau 1764), and finished by »About timber transportation, conservation, and material strength, with an emphasis on ship building« (Duhamel du Monceau 1767). The texts clearly indicate the rationale, providing the timber required for the fortifications of the French army, and the timber required building war ships for the French Marine. We characterize this first phase of development as »***utilization paradigm***« because it was mainly motivated by the increasing demand of timber for government use. The accurate description of structural aspects is the beginning of organized theoretical knowledge in almost any field (Boulding 1956). In our field of interest it is mainly a systematic survey of tacit knowledge embodied by practices that evolved form trial and error and defined by rules of thumb.

2.2.2 Tayloristic Paradigm – *Taylorova paradigma*

The emergence of industrial engineering as a scientific discipline at the beginning of the 20th century induced (1) the systematic study of work processes by time studies, and (2) the development of formal training based on the assumption that there is one »single best practice« that can be derived by scientific investigation of work elements and by systematically rearranging them by using performance metrics. There are hints that Vauban – the well-known French fortification specialist – was probably the first to do work studies (Hilf 1926), which would become a guiding methodology 150 years later when Fredric Taylor's seminal texts on time studies and piece-rate systems (Taylor 1895), on shop management (Taylor 1903), and on scientific management (Taylor 1911) triggered a punctuated discontinuity of development. We call this second phase of development »***Tayloristic Paradigm***« because it changed the conceptual world view on labor into a mechanistic clockwork system that could be designed and controlled deterministically. It also had a decisive effect on the philosophy of worker training. For centuries, personal observation was the mean to acquire skills and competences. Taylor's concept of time studies got into forestry at about 1910 (Braniff 1912) and resulted in the first formal description of the »***piece-***

volume-law« that expresses the principle that time consumption per unit of volume decreases with increasing volume per work piece (Ashe 1916, Strehlke 1927). The new paradigm, that Hilf (Hilf 1926) described »Die Zahl herrscht – Das Gefühl muss schweigen« [Numbers are ruling – the feeling has to be silent«; translated by the author] initiated the establishment of scientific groups dedicated to the study of forest work. The Institute of Forest Work Science (Hugo H. Hilf, Germany), founded in 1927, should become a nucleus for the emergence of forest work science. In 1927, Alexander Koroleff started his work at the Woodlands Section of the Canadian Pulp and Paper Association CPPA (Sundberg 1988), resulting in a series of green covered texts dealing with pulpwood cutting, skidding, hauling, driving, road construction and forest management, which set a standard, worldwide, for work in this field (Sundberg 1988). Roughly in 1912 the United States Forest Service established a *Logging Engineering Division* within the Office of Silviculture (Girard 1917), out of which came a number of pioneering studies (Ashe 1916, Girard 1917, Girard 1922). However, manual work and horse logging were dominating through the »Tayloristic Paradigm« period (Koroleff 1952), and the Second World War stopped mechanization efforts and even lead to serious reversals.

2.2.3 Mechanization Paradigm – *Paradigma mehanizacije*

During the Second World War important new theories were developed to solve pressing engineering problems (Sheridan 1985). Off-Road-Locomotion was one of the decisive problem drivers that triggered mechanization of forest operations after Second World War. This third period of development (Fig. 1), starting around the 1950s, was dominated by the »***Mechanization Paradigm***«, because research efforts aimed at substituting the production factor »work« by the production factor »capital«. The awareness for logging mechanization spread, mainly from the USA and Canada, to Europe and the USSR at the end of the reconstruction period of 1923-1927 (Koroleff 1952). However, major progress occurred when government efforts were made after Second World War in the USA (Forest Service Technology and Development (formerly Equipment Development and Testing) Program), the USSR (Central Research Institute of Logging Mechanization and Power Sources in the Forest Industry ZNIIME (Koroleff 1952), and Canada (Mechanization Steering Committee of CPPA Woodlands Section in 1948 (MacDonald and Clow 2003)) to promote the development of logging machinery. These efforts resulted in three types of new machinery that should trigger a kind of revolution of logging practices: (1) the power saw, (2) the skidder, and (3) the truck for on-road transportation. In parallel, governments built laboratories to study the body measures and the physiological performance of populations that would be machine operators (mainly pilots, sailors, soldiers), resulting in the establishment of a new scientific discipline, known as *»human factors engineering«* in the USA, or *»ergonomics«* in the UK (Sheridan 1985). Additionally, methods of mathematical statistics, originally developed by R.A. Fisher (Fisher 1925, Fisher 1935) entered the field of forest operations, changing both experimental design and data analysis (Steinlin 1987).

The years from 1950 to 1970 were the period of greatest activity in the development of mechanization. They led to a series of outcomes that were essential for the consolidation of forest operations as a scientific discipline. First, the establishment of an invisible college could be observed (Silversides 1988). An invisible college refers to a small group of researchers that regularly exchange information about the newest progress on the research front, and that maintain personal relationships. The most important scholars of this invisible college were: Ivar Samset, Norway; Ulf Sundberg, Sweden; Hansjürg Steinlin, Switzerland/Germany, Kalle Putkisto, Finland; C. Ross Silversides, Canada; Louis-Jean Luissier, Canada; Tom Walbridge, USA; Peter Koch, USA; Konstantin S. Voronitsin, U.S.S.R.; Ivan Klemenčić, Yugoslavia; and others (Sundberg 1988). Second, a formal structure for the international exchange of scientific information established when the International Union of Forest Research Organizations, IUFRO, implemented a new organizational structure at the world Congress of 1948 (Zürich, Switzerland), consisting of 11 sections, one of which was section 32 »operational efficiency«. The section leaders were: G. Luthman (Sweden, 1949), G. Callin (Sweden, 1950), U. Sundberg (Sweden 1951–1961), I. Samset (Norway, 1962–1967). B. Ager (Sweden, 1968–1971). Third, a number of university professorships were created and filled (Sundberg 1988). In 1949, the Royal College of forestry, Sweden, implemented a professorship on operational efficiency that was headed from 1949 to 1951 by G. Luthman and from 1952 to 1985 by U. Sundberg. Similar professorships were formed in Germany in 1955 (Göttingen, Gläser) and in 1958 (Freiburg, H. Steinlin). In 1956 Ivar Samset started office in As, Norway, and in 1963 the University of New Brunswick filled similar positions with L. Seheult and T. Bjerkelund. The influence of the mechanization period has still been ongoing. There are still several professorships named »forest mechanization«, especially in Eastern and Southern Europe.

Table 1. Systems-oriented analytical approaches to advice decision- and policy-makers, following (Quade 1968a)
Tablica 1. *Analitički pristupi orijentirani prema sustavu za savjetovanje donositelja odluke i kreatora politike (Quade 1968a)*

Type of Analysis *Vrsta analize*	Goals of Analysis *Ciljevi analize*
Analysis of Major Policy Alternatives [Strategy / Policy Analysis] *Analiza glavnih političkih alternativa* *[Analiza strategije / politike]*	Determine a portfolio of future activities and identify the means to achieve it by evaluating own basic values and the probable intentions of others. *Utvrditi područja budućih aktivnosti i načina za njihovo ostvarivanje procjenom vlastitih temeljnih vrijednosti i vjerojatnih namjera drugih.*
Design and Development of New Systems [Systems Analysis] *Oblikovanje i razvoj novih sustava* *[Analiza sustava]*	Plan, design or control new systems to improve existing operations or to implement operations that were never performed before. Analyze what the requirements are, how they can be best achived and what the trade-offs are. *Planirati, oblikovati ili kontrolirati nove sustave za poboljšanje postojećih radova ili za primjenu radova koji nikad prije nisu primijenjeni. Analizirati zahtjeve, kako ih najbolje ostvariti i koje ustupke pritom treba učiniti.*
Choice of Alternatives [Cost-Effectiveness Analysis] *Odabir alternativa* *[Analiza djelotvornosti i troškovne isplativosti]*	Chose courses of actions out of a set of alternatives that maximize effectiveness-cost. *Odabrati tijekove djelovanja iz niza alternativa koji dovode do najveće djelotvornosti i troškovne isplativosti.*
Management of Operations [Operations Research] *Upravljanje radovima* *[Istraživanje radova]*	Increase efficiency man-machine systems in a certain context. *Povećati djelotvornost sustava čovjek – stroj u određenom kontekstu.*

Increasing complexity – *Porast složenosti*

Increasing structuredness – *Porast strukturiranosti*

2.2.4 Systems Paradigm – *Paradigma sustavâ*

The development of a variety of machines led to an exponentially increasing complexity due to the increase of options for a specific operation. Additionally, some of the thinkable concepts were so novel that their exploitation could not be poorly planned on the basis of traditional experience. There was a lack of approach to evaluate the best sequence of harvesting, processing, transportation, and materials handling processes (Silversides 1988). Similar types of problems occurred in military technology during the second world war, and triggered the development of new theories to solve pressing engineering problems (Sheridan 1985). Nowadays, this area of knowledge is known as systems theory, covering several scientific fields, such as systems engineering, systems analysis, and theory of control. The first attempts to follow a systems approach to solve operational problems in forestry goes back to the 1950s (Silversides 1988). However, serious application of systems theory entered forest operations only at the beginning of the 1970s (Hopper 1973). We characterize this fourth phase of development as »***systems paradigm***«, because it totally changed the way of thinking and lead to a set of highly-mechanized harvesting systems that have been dominant for many years.

The essence of the systems approach is to identify or recommend a course of action or a set of actions that best fit with a set of objectives. It aims at »*using an appropriate framework – in so far as possible analytic – to bring expert judgment and intuition to bear on the problem*« (Quade 1968b), what could be seen as »*mechanization of brainwork*«. Quade (Quade 1968a) presented a framework to classify and characterize the type of problems to be tackled by systems analysis (table 1). Management of operations, the first level of analysis, aims at increasing the efficiency of man-machine systems in a certain context. This type of problem is usually of low complexity and high structuredness. The second level of analysis aims at choosing courses of actions out of a set of alternatives that maximize some effectiveness-cost measures. The third level of analysis addresses the design and control of new systems to improve existing operations or to implement operations that were never performed before. The fourth level of analysis, strategy or policy analysis, aims at investigating a portfolio of future activities and at identifying the means to achieve them. The fourth level of analysis is characterized by high complexity and low structuredness. Quade's framework (table 1) is continuing to be useful.

During the 1960s, a Swedish group at Skogsarbeten [Swedish Logging Research Foundation] explored an approach based on systems theory (Hedbring and Åkesson 1966, Hedbring et al. 1968) aiming at developing novel harvesting systems that followed the vision »*no man on the ground, no hand on the wood*« (Lundell 2003). Researchers of the Logging Development Program of the Canadian Forest Service adapted the Swedish report to North American conditions (McCraw and Silversides 1970).

Systems engineering is an interdisciplinary process to transform needs, requirements, and constraints into a system solution throughout the systems lifecycle (IEEE 1998). The systems engineering process tackles a design problem by stepwise refinements, going top-down through three phases: (1) system definition, (2) preliminary design, and (3) detailed design. The functional architecture is the main outcome of the systems definition phase (IEEE 1998), describing the (1) arrangement and (2) sequencing of system functions. The Swedish study identified five processing functions (fell, delimb, buck, debark, chip) that could be allocated to four processing locations (stand, strip trail, truck road, landing). Considering, that the felling process has to occur in the stand there are 256 possibilities to allocate processing functions to processing locations. 26 of them were selected for further investigation, while 15 were used for detailed analysis (Hedbring et al. 1968). The next step of the systems engineering process had to group functions that are allocated to machine concepts. The study identified 14 mobile processing and three off-road transportation machine concepts that built the framework for productivity and cost analysis. This Skogsarbeten study (Hedbring et al. 1968) had far-reaching impacts. First, it defined the classes of harvesting systems (cut to length, tree length, full tree) and the corresponding types of harvesting machines (for example feller-buncher, feller-delimber-bucker [nowadays known as harvester], delimber-bucker [known as processor], etc.) that are still in use today. Second, it identified a full-mechanized cut-to-length harvesting system consisting of a harvester and forwarder that has been decisive for mechanized harvesting operations in many countries of the world.

Systems analysis in a broader sense (table 1) provides analytical tools and methods for the design and control of new systems to implement operations that were never performed before (Quade 1968b). Simulation of harvesting systems first emerged within the logging development program of the Canadian Forest Service under the leadership of C. Ross Silversides (MacDonald and Clow 2003, Silversides 1988). The rational for the simulation studies was to evaluate the functional requirements and the corresponding trade-offs for a range of operational scenarios (Newnham 1967b). Simulated testing has many advantages over field testing (Newnham 1967b). First, the method is very rapid. Second, it is possible to vary machine parameters without the expense of modifying a real machine. Third, machines can be tested in a wide range of stand conditions using data from either actual or hypothetical stands. Fourth, several tests may be made in the same stand, thus eliminating the »between stand« variation. Fifth, it makes it possible to study the effect of varying one stand or machine parameter while keeping the remaining characteristics constant. The main efforts to simulate novel machine concepts took place between 1966 and 1971. The first simulation model was very simple and restricted to two machine types (Newnham 1966). It was continuously revised and improved (Newnham 1967a, b) and resulted, in cooperation with the Royal College of Forestry, Sweden, and the Swedish Logging Research Foundation, in the so-called Newnham-Sjunnesson model (Newnham 1970, Newnham and Sjunnesson 1969). The model was later adapted to consider the prevailing requirements of North American conditions, harvesting larger trees mainly in clear felling operations. The resulting model, CANLOG (Newnham 1971), has been used extensively by one major Canadian manufacturer to test several machine concepts and to select the specifications for the detailed design. However, those simulation models could not be used for comparing machines from different harvesting systems, nor could it be used to see how a new machine concept might fit into existing harvesting systems.

Systems analysis in a more narrow sense, often called operations research, aims at increasing efficiency of man-machine systems in a certain context (table 1). Harvesting researchers realized that increasing mechanization by itself is not sufficient to improve stand to mill operations (Newnham 1973). Therefore, increased emphasis was placed on planning, scheduling and control of harvesting and transportation operations (Newnham 1973). Although technof systems analysis were used as early as 1955 to improve harvesting operations, they were limited and generally did not account for the interactions of topography, timber size, timber distribution, personnel, and machinery (Bare et al. 1984). Increasing computing power and the availability of more sophisticated methods resulted in a takeoff of operations research methods related to forest operations. In 1976, two seminal contributions were published. Dykstra was the first who simultaneously optimized the spatial layout of cutting units and the selection of harvesting systems (Dykstra 1976, Dykstra and Riggs 1977). At the same time Weintraub concurrently solved the optimization of timber management activities, road construction activities and transportation activities with a mixed-integer approach (Weintraub and Navon 1976). Dykstra and Weintraub were the door openers to a huge opportunity-space offered by the methods of operations research. Subsequently, a new research stream emerged, resulting in a forest operations specific body of knowledge (Church et al. 1998, Martell et al. 1998, Weintraub and Bare 1996).

2.2.5 Network Paradigm – *Paradigma mreže*

The traditional view consisted of a dichotom characteristics of human and artificial systems (Berners-Lee 1998). Whereas artificial systems have been seen as working purely mechanically, it was clear that humans have the capabilities to solve ill-structured, complex problems by using heuristics and intuition. The design of socio-technical systems was therefore done with static allocation of functions, what means that the division of tasks between humans and machines was fixed by the designer (Lee 2001). The increasing allocation of tasks to machines and systems lead therefore to an increasing degree of static relationships between the systems components, resulting in a loss of flexibility, expandability and adaptability to changing manufacturing environments. Centralized, hierarchical systems with static interactions often lead to situations where the whole system shut down by a single failure at one point (Colombo et al. 2006). One promising structure to overcome this problem is to have a conglomerate of distributed, autonomous, intelligent, fault tolerant, and re-usable processing units, which operate as a set of cooperating entities (Colombo et al. 2006). The World Wide Web technology provided the possibility to store random associations between disparate things (Berners-Lee 1998). The dream behind the Web was to create a common information space in which we communicate by sharing information that would be so generally used that it became a realistic mirror of the ways in which we work, play and socialize (Berners-Lee 1998). Internet technology should become the key technology driver to allocate tasks dynamically, meaning that the division of tasks between humans and systems only depends on the moment to moment allocation. Dynamic function allocation requires a new description of the interaction between systems and humans because swarms of agents are adapting to the environment in unpredictable ways. This could even lead to the characteristic behavior of complex, adaptive systems, characterized by self-organization and emergence of new properties (Colombo et al. 2006). We call this fifth, ongoing phase of development ***»network paradigm«*** (Moridera et al. 2000). It will transform the way people live and interact, although we are at an early, not mature, stage of this new paradigm (Davis and Stephenson 2006).

The network paradigm is characterized by dynamic allocation of functions to cells and links between cells. Therefore, it opens new ways of cooperation and interaction between humans, and complex »man-made« systems. However, the change of technology is much faster than the change of management structures, what is called »second generation management applied to fifth-generation technology« (Savage 1990). This mismatch of technology and management often resulted in failures of new approaches. A novel approach, called business process reengineering, aims at closing this gap by concurrently re-designing and controlling technical and administrative processes. Porter's seminal work on the value chain (Porter 1985) identified nine primary activities, (1) inbound logistics, (2) operations, (3) outbound logistics, (4) marketing and sales, (5) service, and for supporting activities, (6) procurement, (7) technology development, (8) human resource management, (9) firm infrastructure, that should dramatically change our way of thinking about manufacturing and operations. Porter's work probably triggered the establishment of »chain«-disciplines, such as logistics and supply chain management. Those »chain«-disciplines entered into the forest operations community with some phase difference by the end of the 1990s (Heinimann 1999), and became a subject of discussion after the 1st World Symposium on Logistics in the Forest Sector (Sjöström 2000), held in 2000 in Helsinki, Finland.

3. The Way Ahead – *Put naprijed*

Following the previous thoughts, we have been entering a phase of development that we characterize by the »network paradigm«. This raises the question where we will be heading? Below, we will discuss some challenges that we will probably been facing. The identification of the challenges is based on two pillars: (1) trends documented in the scientific literature, and (2) the personal experience of the author as a coordinator of the division »forest operations engineering and management« of the International Union of Forest Research Organizations IUFRO. Below, we will first sketch a possible vision, how operations systems could look like in 2020, next propose a definition of our scientific discipline, and then discuss some challenges in four areas of activity: (1) harvesting and transportation engineering, (2) forest operations management, (3) forest ergonomics, and (4) forest operations ecology. We are aware, that the discussion of future trends will always be biased by the perceptions, values and expectations of the author.

3.1 2020 Vision – *Vizija 2020.*

In 2020 forest operations system will be network-systems of self-organized »cells« [holons] that

⇒ are ***autonomous, cooperative building blocks*** for transforming, transporting, storing, and/or validating physical objects and information;

⇒ have some ***machine intelligence*** to control actions autonomously and to negotiate and cooperate with other entities [distributed, coordinated decision-making]

⇒ consist of (1) an ***information processing part*** (software) and (2) a ***physical processing part*** (hardware).

Several emerging concepts that advocate intelligent and distributed manufacturing structures have been reported in the literature. A new generation of manufacturing systems is referenced as holonic manufacturing systems and is characterized by a set of distributed, autonomous, intelligent units that have the capability to negotiate, to cooperate, and to self-organize (BMED 1998, Colombo et al. 2006). The word »holon« describes the hybrid nature of the whole and its parts. Holons are »sufficiently autonomous self-reliant units that have a degree of independence and handle situations without asking higher authorities for support« (Colombo et al. 2006).

Accordingly, our scientific discipline, forest operations engineering and management, can be defined as follows[1]:

Forest operations engineering and management research aims at (1) understanding the fundamental principles that underlie the behavior of forest operations systems and at (2) developing concepts, methods and tools that support the design, the implementation, the operation, and the continuous improvement of these systems. It is problem-oriented, aiming to provide designs, plans, schedules, and control mechanisms that are:

⇒ ***bio-physically effective****, considering the physical laws, engineering principles, and environmental relationships of forest ecosystems,*

⇒ ***economically efficient****, considering the costs and benefits of short and long range consequences,*

⇒ ***individually compatible****, considering to prevent adverse health effects, prevent adverse effects on the psychosocial well-being, foster the development of personal skills and attitudes, and promote social reasonability,*

⇒ ***environmentally sound****, considering impacts on the natural and social environment and efficient use of resources including non-renewable materials, renewable materials, water, energy, and space,*

⇒ ***institutionally acceptable*** *considering laws, regulations, and informal rules governing the forest operation, landowner objectives, and social values.*

The underlying research paradigm represents operations systems as flow networks and uses mathematical models to describe its behavior and to evaluate the efficiency, effectiveness and environmental performance of alternate policies, strategies, and practices. The operations core is a system that includes research, design, engineering, production within operating units, networks of information and material flows that tie operating units together, and the development, distribution and delivery of goods and services to customers.

Forest operations engineering and management has always been borrowing concepts and models from »umbrella«-disciplines, such as industrial engineering, operations management, ergonomics, or industrial ecology. We have to be interested in maintaining the inspiring influence of »mother« and »neighboring« disciplines, and in demonstrating that we have strong links to those »umbrella«-disciplines. This is why the International Union of Forest Research Organizations renamed the field of research from »Forest Operations« to »Forest Operations Engineering and Management«.

3.2 Challenges in Harvesting and Transportation Engineering – *Izazovi u inženjerstvu pridobivanja i prijevoza drva*

Harvesting and transportation engineering consists of analysis, design and continuous improvement of the facilities and networks of technical and transaction processes required to harvest and to transport biomass and/or non-wood products from the stump site to mill facilities. The corresponding clusters of primary processes are (1) tree conversion, (2) off-road transportation, (3) material handling, and (4) on-road transportation. Classes of transaction processes are (5) procurement, (6) order fulfillment,

[1] This definition is a further development of former work (Heinimann 1995, Sundberg 1988, Samset 1992). The author is also grateful to John Sessions and John Garland, Oregon State University, for the valuable discussions that led to the present understanding. – *Ova je definicija nastavak razvoja prijašnjega rada (Heinimann 1995, Sundberg 1988, Samset 1992). Autor zahvaljuje Johnu Sessionsu i Johnu Garlandu na dragocjenim razgovorima koji su doveli do današnjega razumijevanja.*

(7) data exchange, and (8) system monitoring and control. The publication »Visionary manufacturing challenges for 2020« (BMED 1998) identified six grand challenges, three of which are relevant for harvesting and transportation engineering. Those are:

⇒ to achieve concurrency in all operations,

⇒ to reconfigure manufacturing enterprises rapidly in response to changing needs and opportunities, and

⇒ to develop innovative manufacturing processes with a focus on decreasing dimensional scale.

The first challenge, concurrency, addresses the problem of distributed systems engineering (including sensor networks, pervasive computing systems, and peer-to-peer systems) (Zambonelli and Rana 2005). The second challenge is related to the increasing need for flexibility. The third challenge, tackling decreasing dimensional scale, is also relevant for forestry. It does not mean the dimension of a work piece, but mainly the dimension of the smallest discrete spatial unit to be managed. The ultimate unit will be the individual tree. In our point of view, harvesting and transportation engineering will be facing the following challenges:

⇒ to develop and/or deploy flexible sensors and control algorithms that provide precision process control in both time and space *[sensor technology as a driver]*,

⇒ to develop and deploy autonomous harvesting and transportation cells that have some control, negotiation, and cooperation intelligence CNCI *[«cell« intelligence as a problem driver]*,

⇒ to disseminate and apply the knowledge on environmentally sound harvesting technologies to developing countries (especially in the tropics) *[transfer of environmentally sound technology as a problem driver]*,

⇒ to disseminate and apply the knowledge on industrialized, highly-mechanized harvesting technologies to countries in transition *[transfer of harvesting system technology as a problem driver]*.

3.3 Challenges in Forest Operations Management – *Izazovi u upravljanju šumskim radovima*

Forest operations management consists of analysis, design, control, and continuous improvement of business processes, such as procurement, order fulfillment, distribution, monitoring and control within firms and business to business (B2B) networks. It measures and analyses internal processes with emphasis on effectiveness, efficiency, and quality by using quantitative models to map and solve related problems of scheduling, inventory, shipment routing, or facility location. The publication »Visionary manufacturing challenges for 2020« (BMED 1998) identified six grand challenges, one of which is relevant for forest operations management: to instantaneously transform information gathered from a vast array of sources into useful knowledge for making decision. In our point of view, forest operations management will be facing the following challenges:

⇒ To move from business management to supply chain management through reengineering business processes (Heinimann 2000, Loch 1998), by (1) adapting standard supply chain operations reference models (e.g. SCOR (Huan et al. 2004)), and by (2) tailoring and implementing business to business (B2B) transaction standards (e,g, -WoodX-XML, StanForD-XML),

⇒ To develop mathematical tools (1) to support distributed, coordinated decision making (e.g. agent-based modeling techniques), (2) to identify near-optimal solutions for complex geographical problem spaces with intelligent search techniques (e.g. genetic algorithms, simulated annealing, etc.), and (3) to link optimization models to on-the-ground conditions by making them spatially explicit.

⇒ To close the substantial gaps between supply chain management theory and practice (Storey et al. 2006) by (1) integrating the body of knowledge into curricula and into mental models of both researchers and practitioners, and by (2) modeling supply networks with generic, static or dynamic process models[2] (Harrison 2002). In our point of view »supply chain management« has often been used as a buzzword to wrap up »*old wine in new bottles*«.

3.4 Challenges in Forest Ergonomics – *Izazovi u ergonomiji šumarstva*

Forest Ergonomics is the area of knowledge dealing with the capabilities and limitations of human performance in relation to design of forest machines,

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[2] A process network is modeled as a mathematical graph in which flows (resources, goods, services) traverse edges, and whose nodes represent activities that transform the flows. – *Mreža je procesa modelirana kao matematički grafikon u kojem se vrijednosti veličina (sredstva, proizvodi, usluge) presijecaju, a presjecišta predstavljaju aktivnosti pri kojima se veličina transformira.*

jobs, and modifications of the physical environment. It seeks to ensure that human's tools, machines, and work systems are best matched to their (1) physical strength, size, and speed and to the capabilities of (2) sense, (3) memory, (4) cognitive skills, and (5) psychomotor preferences. The field of knowledge is also termed human-factors engineering, or human engineering.

The ultimate goal of ergonomics has been to create humane working conditions. It is similar to engineering in that it is heavily designed oriented (Brewer and Hsiang 2002). Humane working conditions have to (1) prevent adverse health effects, (2) prevent adverse effects on the psychosocial well-being, (3) foster the development of personal skills and attitudes, and (4) promote social reasonability (Ulich 1992). Since the nature of work is not stable, but changes with the developments in technology and society, the contents of ergonomics must also change (Hollnagel 2001). Three streams of ergonomics may be identified: (1) »classical economics«, tackling with body-work compatibility, (2) »cognitive ergonomics«, aiming to improve mind-work compatibility, and (3) »control ergonomics«, investigating system-goal compatibility (Hollnagel 2001). Classical ergonomics has been existing for about 60 years (Sheridan 1985), resulting in a considerable body of knowledge. Compared to manufacturing industries, the forest sector still has a lot of workplaces at which muscular work has been dominating. This is especially true for developing countries and for countries in transition. Countries with a highly industrialized forest sector, such as is the Nordic countries, mainly provide workplaces at which cognitive work has become dominating, and which are increasingly influenced by computerization (e.g. harvester-operator workplace). In our point of view, forest ergonomics will be facing the following challenges:

⇒ To disseminate the *knowledge of classical ergonomics* to developing countries and to implement and enforce working standards adapted to location-specific, often harsh working conditions and to biomechanical and physiological characteristics of the workers.

⇒ To improve the *human-software interface* to empower people and to leverage cognitive, perceptual, and collaborative skills (Hoffman et al. 2002).

⇒ To overcome the *problem of »2nd generation management applied to 5th generation technology* (Brewer and Hsiang 2002) by macroergonomic redesign of the human-organization interface (Hendrick 2002, Kleiner 2002, 2004, 2006).

⇒ To tackle the problem of socially distributed cognition and cooperation, resulting from the introduction of distributed, holonic manufacturing systems (Lee 2001, Rasmussen 2000, Sheridan 1985).

3.5 Challenges in Forest Operations Ecology – *Izazovi u ekološkoj pogodnosti šumskih radova*

Industrial Ecology is a scientific discipline that investigates human transformations of mass and energy from an ecosystem perspective (Ehrenfeld 2004, Erkman 1997, Kay 2002). Ecosystem perspective refers to the analysis and design of biophysical mass and energy transformation systems in order to maintain a situation which is ecologically sound, while providing humans with a sustainable livelihood. Forest Operations Ecology applies the principles of Industrial Ecology to Forest Operations Systems. It aims to develop and deploy environmentally sound forest operations technologies, to use resources efficiently, to minimize the overall production of waste and emissions, and to minimize impacts to structures and functions of environmental spheres (atmosphere, biosphere, hydrosphere, and lithosphere). The publication »Visionary manufacturing challenges for 2020« (BMED 1998) identified six grand challenges, one of which is relevant for forest operations ecology: to reduce production waste and environmental impacts to »near zero«. In our point of view, forest operations ecology, which is an operational approach to sustainability (Erkman 1997), will be facing the following challenges:

⇒ To adapt environmental performance indicators EPIs and environmental state indicators ESIs, as proposed by the ISO 14021 standard, to, and to establish a set of environmental performance standards for forest operations systems,

⇒ To analyze and evaluate environmental performance of harvesting and transportation systems by using Life Cycle Assessment LCA, or Substance Flow Analysis SFA,

⇒ To develop standards to monitor and report environmental performance metrics.

4. Conclusions – *Zaključci*

The voice of forest operations within the family of scientific communities has been weak. The forest operations community faces the problem of improving its scientific visibility, realigning its research efforts to the future challenges, and of strengthening its self-confidence. The paper aimed at (1) exploring the concept for worldviews (paradigms) that shaped the scientific development, (2) sketching a vision how forest operations could look like in 2020, (3) establishing a common understanding for the future of our discipline, and (4) discussing the major challenges that we will probably been facing.

The investigation resulted in three major findings. First, five paradigmatic periods of developments could be identified: the utilization paradigm, the Tayloristic paradigm, the mechanization paradigm, the systems paradigm, and the network paradigm. Second, we are presently entering a new phase of development, characterized by the »network paradigm« that consists of network-based forest operations systems that are built of self-organized »cells«. Third, those network-based, self-organizing systems will face us with some challenges. The concurrency of spatially distributed coordination and operation activities is one of those challenges, requiring management to go from arts to science. Algorithmic methods and control processes will be a backbone of distributed, coordinated decision-making, and of supply chain management. Forest ergonomics will face the challenge to overcome the problem of »2nd-generation management applied to 5th-generation technology« by redesigning the human-organization interface. The quantification of the »industrial metabolism« of forest operations systems will be another challenge that we have to tackle with. It will hopefully move environmental performance evaluation from »good feelings« to hard facts.

The author intended to trigger a broad discussion on the future direction of our discipline, forest operations engineering and management, and to induce the redesign of curricula. This is going along with his vision that the forest operations engineering and management community will regain its strengths and become more visible within the family of scientific communities.

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Sažetak

Šumarsko inženjerstvo i upravljanje šumskim radovima – osvrt na put unazad i naprijed znanstvene discipline

Rad opisuje pet paradigmi faza razvoja, prikazuje viziju sustava izvođenja šumskih radova 2020. godine, predlaže definiciju šumarskoga inženjerstva i upravljanja šumskim radovima kao znanstvene discipline, te razmatra izazove za inženjerstvo pridobivanja i prijevoza drva, upravljanje šumskim radovima, ergonomiju u šumarstvu i ekološku pogodnost šumskih radova.

Znanstvene su se discipline stalno razvijale slično biološkim sustavima. Kuhn je (1970) pružio model »isprekidane ravnoteže« za znanstvene discipline, u kojem je razdoblja stabilnoga stanja nazvao »normalna znanost«, a razdoblja diskontinuirane promjene »znanstvena revolucija«. Uveo je naziv »paradigma« za određivanje specifičnoga razdoblja stabilnoga stanja »normalne znanosti«, koji definira znanstvenu misao, određuje značajne probleme i oblikuje vrstu pitanja koje treba istražiti. Pri tome se kroz povijest može prepoznati 5 paradigmi: paradigma korištenja, Taylorova paradigma, paradigma mehanizacije, paradigma sustava i paradigma mreže.

Istraživanje se temelji na pretpostavci da se evolucije šumarskoga inženjerstva i upravljanja šumskim radovima može odrediti dvjema glavnim dimenzijama: (1) znanstvenim teorijama i postupcima (os x na slici 1) te (2) uočenom i istraženom razinom složenosti proučavanih objekata (os y na slici 1).

Organiziranje šumskih radova zbog potražnje tržišta otpočelo je u 17. stoljeću te se paradigma korištenja definira uglavnom povećanjem potražnje za drvom. Pojava industrijskoga inženjerstva kao znanstvene discipline na početku 20. stoljeća potaknula je sustavno ispitivanje radnih procesa studijem rada i vremena te razvoj temeljne obuke radnika. Taylor (1895, 1903, 1911) uvodi studij rada i vremena kao vodeću metodologiju te se stoga druga faza razvoja nazova Taylorova paradigma jer dolazi do promjene gledišta na rad koji se može deterministički oblikovati i kontrolirati. Taylorovom paradigmom započinje osnivanje znanstvenih skupina posvećenih istraživanju šumskoga rada. Uvođenjem studija rada i vremena u šumarstvo nastaje »zakon obujma komada« koji objašnjava da se utrošak vremena po jedinici proizvoda smanjuje s povećanjem obujma komada.

Problem kretanja po bespuću bio je odlučujući za pokretanje mehaniziranja šumskih radova nakon Drugoga svjetskoga rata. Od 1950. do 1970. godine vrijeme je najvećega razvoja mehaniziranja radova, a utjecaj toga razdoblja očituje se i danas. To se razdoblje razvoja naziva »paradigma mehanizacije«. Znanstveni napori urodili su trima tipovima novih strojeva koji su pokrenuli revoluciju pridobivanja drva: motorna pila, skider te kamion za prijevoz drva. Usporedno se razvija nova znanstvena disciplina: ergonomija.

Razvoj različitih strojeva doveo je do složenosti izvođenja šumskih radova jer ima više rješenja za izvođenje određenoga šumskoga rada. Stoga se javlja potreba procjene najprikladnijih radnih procesa u pridobivanju drva. Razvijaju se nove teorije za rješavanje problema poznate kao »teorija sustavâ«, koja obuhvaća inženjerstvo sustava, analizu sustava i teoriju upravljanja. To se razdoblje može imenovati kao paradigma sustavâ jer je promijenila način mišljenja i dovela do uvođenja visoko mehaniziranih sustava pridobivanja drva koji će biti dominantni dugi niz godina. Quade je (1968a) prikazao razvrstvanje problema s kojima se bavi analiza sustava (tablica 1). Analiza sustava određuje metode za oblikovanje i upravljanje novih sustava koje treba uvesti u radove. Pri tome simulacija istraživanja pokazuje mnoge prednosti nad terenskim mjerenjima: brža je, moguće je mijenjati parametre strojeva bez troškova prilagodbe stvarnoga stroja za mjerenja, stroj se može ispitati u širem opsegu sastojinskih uvjeta temeljenih na podacima stvarnih ili hipotetskih sastojina te se može eliminirati prirodna varijacija između sastojinskih uvjeta. Sustavna analiza u užem smislu ima cilj da se poveća učinkovitost sustava čovjek – stroj.

Daljnje povećanje zadataka prema strojevima i čitavu sustavu dovodi do statičkih odnosa između sastavnica sustava rezultitrajući gubitkom fleksibilnosti i prilagodbe sustava. Centralizirani sustavi sa statičkim odnosima izazivaju prekid zbog greške jedne sastavnice. Nova struktura za prevladavanje problema mora biti mješavina autonomno raspodijeljenih, inteligentnih, greškovno tolerantnih i uvijek upotrebljivih izvedbenih jedinica. Internetska tehnologija postaje ključni pokretač tehnologije stvarajući prostor za razmjenu informacija i dinamičku raspodjelu zadataka. Ta se faza razvoja naziva mrežnom paradigmom koju karakterizira dinamička raspodjela radova između jedinica i povezivanje jedinica uz mogućnosti novih načina suradnje i međudjelovanja ljudi i složenih sustava.

Porter je (1985) utvrdio devet aktivnosti koje bi trebali dramatično promijeniti način razmišljanja o proizvodnji i izvođenju radova: ulazna logistika, radovi, izlazna logistika, marketing i prodaja, usluge i aktivnosti

podrške, dobava, razvoj tehnologije, upravljanje ljudskim potencijalima, infrastruktura poduzeća. Porterov je rad potaknuo osnivanje mnogih disciplina poput logistike i upravljanja lancem dobave, koje su ušle u područje izvođenja šumskih radova.

Cilj je šumarskoga inženjerstva i upravljanja šumskim radovima razumijevanje osnovnih načela koja čine podlogu ponašanja sustava šumskih radova i razvoj koncepata, metoda i alata koji podržavaju oblik, primjenu, rad i stalno poboljšanje tih sustava. Ova je znanstvena disciplina orijentirana prema problemu s ciljem pružanja oblika, planova, rasporeda i mehanizama kontrole koji su:

⇒ *biofizički učinkoviti s obzirom na fizikalne zakone, načela inženjerstva te okolišine odnose šumskih ekosustava*

⇒ *ekonomski učinkoviti s obzirom na troškove i koristi kratkoročnih i dugoročnih posljedica*

⇒ *individualno usklađeni s obzirom na sprječavanje negativnih učinaka na zdravlje, sprječavanje negativnih učinaka na psihosocijalnu dobrobit, njegovanje razvoja osobnih vještina i stavova i promicanje socijalne razboritosti*

⇒ *okolišno prihvatljivi s obzirom na utjecaj na prirodni društveni okoliš i učinkovitu uporabu prirodnih resursa uključujući neobnovljive i obnovljive izvore, vodu, energiju i prostor*

⇒ *institucionalno prihvatljivi s obzirom na zakone, odredbe te preporuke u skladu s izvođenjem šumskih radova, ciljevima zemljoposjednika (šumovlasnika) i društvenim vrijednostima.*

Inženjerstvo pridobivanja i prijevoza drva naći će se pred problemima dosezanja konkurentnosti u izvođenju svih radova, pred potrebom restrukturiranja proizvodnih poduzeća radi prilagodbe na promjene i razvoja inovativnih radnih procesa. Stoga će morati doći do razvoja fleksibilnih kontrolnih algoritama koji će omogućiti precizno upravljanje radnim procesima u vremenu i prostoru, razvoja autonomnih jedinica pridobivanja drva i transporta s upravljačkom i suradničkom inteligencijom, primjene znanja o okolišno prihvatljivim tehnologijama pridobivanja drva u zemljama u razvoju te primjene znanja o visoko mehaniziranim tehnologijama u zemljama u tranziciji.

Upravljanje šumskim radovima suočit će se s potrebama pomaka poslovnoga upravljanja prema upravljanju lancem dobave drva primjenom referentnih modela radova, razvoja matematičkoga oruđa za donošenje odluka i prepoznavanja optimalnih rješenja za složene probleme pomoću inteligentnih tehnika (genetički algoritmi), povezivanja modela optimizacije s terenskim uvjetima te premoštavanja razlika u teoriji i praksi upravljanja lancem dobave.

Ergonomija u šumarstvu suočit će se s izazovima kako proširiti znanje opće ergonomije u zemljama u razvoju i uvesti norme rada prilagođene specifičnostima područja, radnim uvjetima i biomehaničkim i fiziološkim osobinama radnika.

Budući se izazovi u izvođenju šumskih radova na ekološko prihvatljiv način očituju u usvajanju okolišnih pokazatelja prema normi ISO 14021, postavljanju skupa okolišnih normi za sustave izvođenja šumskih radova i normi za praćenje i izvještavanje o okolišnom načinu izvođenja radova te uvođenje analize i ocjenjivanja okolišnoga utjecaja.

Namjera je autora bila da potakne širu raspravu o budućem usmjeravanju naše discipline, šumarskoga inženjerstva i upravljanja šumskim radovima, te da potakne preoblikovanje nastavnoga programa. To ide zajedno s autorovom vizijom da će znanstvena disciplina šumarsko inženjerstvo i upravljanje šumskim radovima vratiti svoju snagu i postati uočljivo u obitelji znanstvenih zajednica.

Ključne riječi: šumski radovi, šumarsko inženjerstvo, paradigme, budući izazovi, znanstvena disciplina, povijesni razvoj

Author's address – *Autorova adresa:*
Prof. Hans Rudolf Heinimann, PhD.
e-mail: hans.heinimann@env.ethz.ch
Institute of Terrestrial Ecosystems
ETH Zurich
Universitaetstrasse 22
CH–8092 Zürich
SWITZERLAND

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