Experiences of Automation Applications

Martin Ollus

Auringonkuja 7 B 4, FIN-02210 Espoo
Tel: 0400 448714, E-mail: martin@ollus.net

KEY WORDS automation history, automation research, personal experience, advances in methodology, advances in technology

ABSTRACT

The paper presents personal experiences from the development and application of automation solutions, mainly in industrial environments, on six different decades spanning from late 1960's to early 2010's and relates them to their historical context. During the covered period tremendous developments occurred in both methodologies and enabling technologies. During and after the Second World War, significant achievements related to automation theories were developed and presented by e.g. Bellman, Wiener and Pontryagin. Also the enormous development of the information technology started after the war. During the described period, the automation field changed from pneumatic based single loop solution to fully digitalised automation with software as a main enabler. In many cases, is the solutions are globally distributed.

In addition to a description of concrete solutions in a chronologic order, their impacts are presented. The paper is concluded by a presentation of lessons learned also giving some thoughts of interesting research and development issues.

1 INTRODUCTION

The paper presents personal experiences from the development and application of automation solutions, mainly in industrial environments, on six different decades spanning from late 1960's to early 2010's. The text is based on a presentation given in an internal seminar /1/. The activities are presented related to the historical context. This relation is studied by considering three dimension, three dimensions are studied: (1) advances in the theory and methodology, (2) development of enabling technologies, especially information and communication technology (ICT), and (3) needs and expectations in the operational environment. Naturally, these dimensions are interdependent via several dynamic relationships. For instance, the globalization, which takes place in the environment, has had an increasing impact on needs and expectations during recent years. Simultaneously, advances in ICT have been an important enabler for globalization. New enablers also contribute significantly to the appearance of new possibilities, which again generate new expectations and needs on the markets.

The paper describes applications of Systems Theory, which is used as a generic term for the disciplines aiming at understanding systems and their behaviour. This understanding of the reality is the basis for automation solutions, which usually use the understanding to cope with the systems, e.g. by anticipating and controlling its future behaviour. In the applications, models of the real systems and their environment play an important role.

In the paper, some personal activities are firstly presented, roughly in a chronological order and in the context of their business and industrial environment, and in the context of advances in theory and technology. The relation between the different contextual issues is further discussed in a summary chapter. Finally, some lessons learned, including some hints for further research, are discussed.

2 EARLY AUTOMATION ACTIVITES

2.1 New theories and computer control

Theoretical achievement during and immediately after the Second World War (Bellman, Wiener, Pontryagin and others) started gradually to impact on the automation area in the 1960's The new achievements were early studied both in research and education also in Finland /2/. An interest in state-of-the art applications, especially control applications of (industrial) processes, arose.

The new solutions and approaches relied on models of the target processes. The methods were not always robust in relation to the models. Consequently, the success of the applications depended on the quality of the used models, how well they described the processes. Many industrial processes are difficult to model. Additionally, they are not linear. These facts lead to extensive interests in modelling and the area of estimation and process identification /3, 4, 5/. However, most of the optimization methods were developed based on linear models. These facts were some of the reasons to the slow penetration of the new findings. It took several decades before more wide applications could be seen.

The application of the new approaches also required computational capacity, which had not been needed e.g. for traditional (analogue) control solutions. In early digital applications in the sixties, the IBM 1710 process computer was used for digital control. This computer was a modification of an older "scientific computer" model IBM 1620. The first successful commercial minicomputer, PDP8, was introduced in 1965 and became soon very popular for industrial applications, also in Finland.

2.2 Computer control in paper production

Because of the role of the pulp and paper industry in the Nordic countries, this industry was a natural application sector for the new achievements. In Sweden, Karl-Johan Åström and Torsten Bohlin developed computer control of the basis weight and moisture of the paper web on paper machines. They made significant contributions for identification of the process models /5, 6/. Almost simultaneously, Juhani Korhonen implemented one of the first Finnish digital control applications for similar paper machine control in Kaukopää during the period 1962 - 1966 /7/. In many of the first digital control applications, "traditional" control methods were applied on digital computers.

Together with Raimo Ylinen, we 1969 - 1971 developed control algorithms for on-line control of the basis weight and moisture of the paper web, supervised by Juhani Korhonen at Nokia. We eagerly studied new methods and recent applications both for identification of process models and for control applications. As a result, some control packages were developed and installed at two different paper mills, Voikkaa Mill in Kuusankoski and Nokia Mill in Nokia. The implementation was made using the new PDP 8 minicomputer. We calculated most of the models using the least-square estimation /8/. For the control, we developed e.g. optimization algorithms with a moving horizon. We also applied some model reference features.

2.3 Some nuclear power applications and their importance

During the 1970's, the first Finnish nuclear power plants in Loviisa were constructed /9/. As the capacity of the plant was planned to be ca 30% of the total power in the Finnish grid, there were concern about the impact on the stability and the control of the grid /10/. In the late 60's, activities were initiated to study the dynamics and the interactions between the plant and the grid using simulation. The capacity of the computers was not good enough to fulfil the requirements for the simulation. Consequently, a hybrid computer (Figure 1), using both analogue and digital computing, was acquired for the purpose /10, 11/.

Fig. 1. Hybrid computer used for simulation of the nuclear power plant and the Finnish grid.

Also the safety of the operation of the plants created concerns, and it was decided to use simulators for training the operators. I moved to VTT in 1972 to participate in the acquisition of such a simulator. We specified both the requirements and the acceptance procedures of the simulator, and performed the acceptance tests, within the frame of a contract between VTT and Imatran Voima, the utility company and receiver of the simulator. Later, the scope was extended to the creation of training programs for the operators /12, 13/.

The activities around the nuclear power program in Finland generated much new research and business e.g. at VTT. Simulation technology became an important RTD area, from which international business also was created (http://www.apros.fi/en/). The work related to operator training initiated research in the operators' work environment. Much of the man/machine and organizational research has its roots there. Also many of the process automation activities at VTT can be considered to be continuation of work started in relation to the nuclear programme.

3 MICROPROCESSORS IN AUTOMATION

Intel introduced the first 4-bit microprocessor in 1971 and a process with an enormous impact in the whole society started. Personally, I became involved in the area at an early stage through two product development projects for automation solutions, based on distributed microprocessor computation. Although the application of new hardware had dramatic consequences, the real impact seems to have been in the possibilities for new applications and the ability to realize new solutions to both existing and emerging needs.

3.1 Seeing and learning sorter

In the mid-70's, VTT got a contract for the development of a system for sorting ore based on latest technological achievements. In the first applications, rocks containing lime stones were separated from side stones based on analyses of the image of the ore. The image was captured by one of the first digital imaging cameras on the market (Reticon). From the captured images, individual rocks and their positions on a running conveyor belt were identified. Features characterizing the rocks were extracted and used to recognize whether a rock was a lime stones or not. Based on the recognition, the side stones were separated mechanically. The sorter (Figure 2) had a high capacity. It could sort tons of ore in a few minutes /14/. The solutions were patented and the patents were later sold to a international company.

Fig. 2. Manual (left) and automatic (right) sorting of ore.

In the realization of the sorter, the new microprocessor technology was used. The first system consisted of 32 independent microcontrollers (Intel 8048) connected to a common communication bus and taking care of the classification of the rocks in parallel. To achieve the needed capacity, the recognition of the individual rocks and their feature extraction were performed by hard-wired electronics.

The sorter had a learning capability. During a learning phase, it formed prototype vectors characterizing both the lime stones and the side stones. In the sorting phase, the features of each actual stone were compared to the prototype vectors using the projection theorem.

The development of the sorter was the very first microprocessor control application in our research group and it was also our first work on image processing. In both areas, the research activities grew fast. However, we tried to keep our applications in the automation domain. The images were considered as measurement inputs for automation purposes and the microprocessors were efficient enablers for the realization of new solutions, e.g. control.

3.2 Digital process automation

In the 1970's, electronic instrumentation systems had largely replaced the previous pneumatic applications. The solutions were analogue until 1975, when Honeywell introduced its microprocessor based distributed digital automation system TDC 2000, which took over the markets for instrumentation systems. In Finland, Valmet started to develop an own digital system, which later got the name Damatic. VTT was deeply involved in the development project, which was considered to be the second biggest software project in Finland so far.

After an intensive development process, the first system was delivered to the Pankakoski paper mill in 1981. The installation contained 101 microprocessor units connected to a communication bus. During the development phase, a second system was sold to Sweden. Damatic was very successful. Valmet became the leading provider of automation systems for the pulp and paper industry, although their systems were used in almost all industrial sectors.

The system performed all functions of the previous analogue (electronic or pneumatic) systems. However, the digital realization enabled a more flexible configuration for different applications. Also the operation from a control room (Figure 3) equipped with a few monitors and keyboards allowed a more convenient use than the previous hard-wired systems, in which every single control loop had its own operation point. In addition, the connection to upper level systems (process computers, production management) was simpler due to the digital technology. These features seem to be some of the reasons to the very good response and fast penetration on the markets for the digital systems.

The Damatic system was realized with technology available around 1980. A continuous concern in the development project was the computing power, both the speed of the processors and the memory sizes. The basic unit called (process station) could handle 16 control loops using one microprocessor and a working RAM-memory of 128k. The program memory EPROM was 4M. To get the needed speed, own fast algorithms had to be developed for several different purposes, e.g. own special fast algorithms for floating operations (multiplication, division, etc.) were used. To efficiently handle the needed actions, an own, simple synchronous operative system was created. Also the packing and allocation of data was a continuous concern /15/.

Fig. 3. Damatic control room.

In addition to the commercial success for Valmet, the Damatic project had a major impact also at VTT, where over 20% of the project development work was done. In many cases, the work at VTT consisted of definitions and specifications of the functionality, but sometimes also concrete software coding were done.

4 FACTORY AUTOMATION

4.1 Advances in manufacturing automation

During the 1980's, information technology entered into the manufacturing area. For example, light microprocessor based CAD systems (e.g. AutoCAD) replaced the previous large and expensive systems. Numerically controlled machines became affordable on the shop-floor, so also industrial robots. Different manufacturing functions (material handling, machining, etc.) were integrated into so called Flexible Manufacturing Systems (FMS). The concept of Computer Integrated Manufacturing (CIM) was introduced to describe the approach to use computers for the control of the whole production process. The new technology achieved a large interest also in Finland /16/. With our own background in using latest information technology for automation purposes, we started to contribute to the research in the area. One main interest was in the concept "flexibility". What were its dimensions, its economic impact, especially on the restructuring of the Finnish industry, including the shift from a heavy industry, with bulk products, towards production of more customer specific products? Especially, we wanted to understand the shift from a heavy industry, with bulk products, towards production of more customer specific products /17/.

4.2 Expansion of the automation domains

The applications of the new information technology increasingly impact on business, working environment, and many other activities and processes in the society. These issues started to largely interest. One result of this interest was a large international programme called TES (Technology, Economy, Society) initiated by the International Institute for Applied Systems Analysis (IIASA) in Vienna in order to study the interactions between these three disciplines. In Finland, SITRA started a national TES program working closely with the project at IIASA. We did both concrete development activities in companies and organizations and more basic research. Also the challenges for regional development were studied. The interactions and the dynamics in the studied areas were summarized in the final report /18, 19/. In addition to the concrete results, the TES program created a large contact network both domestically and internationally. It also formed the basis for later research on manufacturing networks and global production. The work on understanding flexibility also created an activity to apply the ideas in a traditional bulk production /20/.

4.3 Intelligent Manufacturing

Applications of information technology and CIM technology enabled new and "intelligent" manufacturing solutions. In 1989, Professor Hiroyuki Yoshikawa, then President of the University of Tokyo suggested global research, industrial cooperation and technology sharing in cooperative projects for the benefit of mankind. Based on his initiative, a collaborative, industry lead research programme, Intelligent Manufacturing Systems – IMS, started in 1995 with the aim to develop the next generation of manufacturing and processing technologies through multi-lateral collaboration (www.ims.org).

From the start of the IMS-activity, Finland and VTT were very actively participating in several of the early IMS-projects, supported by TEKES. The projects had industrial and research partners from several European countries, US, Japan, Australia and Canada. In these projects, some of the foundations for collaborative manufacturing were studied and solutions developed and demonstrated together with global manufacturing enterprises /21/.

5 GLOBAL NETWORKS

5.1 Production networks

In the beginning of the millennium, an interest in network management appeared globally. As a continuation of the IMS activities, we got involved in several international collaborative research projects, dealing with issues related to the management of networked manufacturing. We also analysed previous and ongoing research in the area and could identify significant on-going activities, but also needs for further research /22, 23/. Especially, a deeper understanding of collaboration was considered to be necessary. The

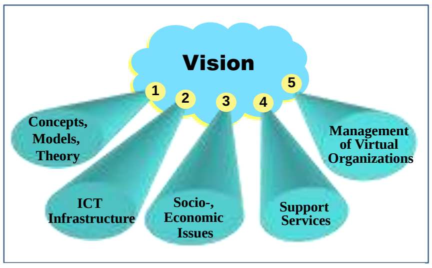

Fig. 4. Research issues for collaborative networks.

area was structured into five specific research issues, which are illustrated in the figure.

5.2 Methods and tools for networking

In line with the research focuses defined above, a European research project (ECOLEAD - European Collaborative networked Organizations LEADership initiative; 2004 - 2008) was initiated to contribute to the development of approaches for a variety of aspects on networking and collaboration. It aimed "to create the necessary strong foundations and mechanisms for establishing the most advanced collaborative and network-based industry society in Europe". In addition to a theoretical frame-work and a reference architecture for collaborative networks, the project developed solutions for different aspects of the management of networks and collaboration in them. All solutions were demonstrated and evaluated in industrial environments, where the project partners were involved /24/. The solutions were related to the following issues:

- Models of collaboration in networks of organizations
- Management systems for breeding environments, replicable to a large variety of sectors
- Coordination principles for Virtual Organizations, adapted to emerging behaviour in complex networks
- Generic and invisible infrastructure and re-utilizable service toolbox, based on interoperability standardization

Many of the solutions were IT based support tools for the management of issues like:

- Trust assessment and maintenance
- Competence management
- Task specific collaboration partner search
- Real-time monitoring and management of collaboration performance
- Virtual organizations management
- Inheritance of experience and knowledge

Although many of the solutions were developed for industrial applications, they have also been adopted to other types of networked organizations. Also the logistics domain has many similar features as e.g. manufacturing networks.

6 SUMMARY OF ACTIVITIES

Some own activities on six different decades are described in the text above. In many of the activities, advances in theory and technology have been utilised. The advances have even enabled completely new solutions. In the figure 5, the activity areas are given on a time line, together with advances in technology, mainly in the ICT area. In many solutions, the ICT development meant that the realisations in the applications increasingly relied on software and collaboration over different types of networks.

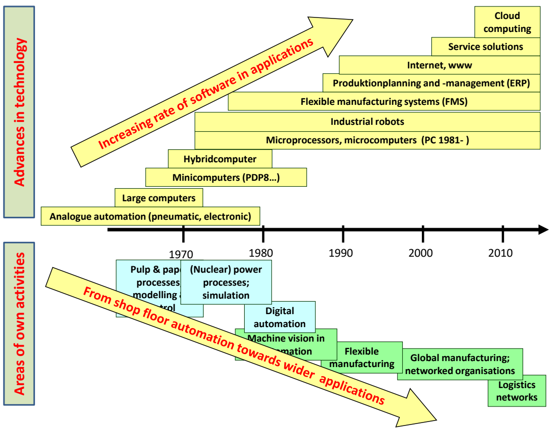

Fig.5. Described activities related to their context.

In the application domain, focus has also gradually switched from technical solutions on the process level ("factory floor") towards higher organisational levels and also include socio-economical processes, like global networking between large sets of organisations. For instance, most of the described solutions since the mid-80's were concentrated on networking and manufacturing related world-wide operations, including logistics. In parallel, the focus of the activities moved from pure technological issues towards a broader interpretation of automation by including human and business aspects. The management of organisations and businesses got an increasing interest.

7 LESSONS LEARNED

In this section, some personal interpretations of the activities and related developments are given. The conclusions are derived by using some systems thinking for understanding causes and consequences.

7.1 Modelling

As all intentional actions require understanding of the object for the actions, models are needed to describe the features of the object and its behaviour. The more complex an object is, the more complex are also the models. They may contain various hierarchical levels from social and organisational models, including human individuals, down to single technical equipment. Additionally, they can be dynamic or static and they may be time or event driven. They can also be mathematical or semantic. Several interacting modelling approach may be needed simultaneously. The interrelationship between different models and modelling approaches seems to become an interesting and challenging issue in the future, as several disciplines and scientific cultures are involved. However, efficient use of models requires that they are as simple as possible in describing the phenomena to be studied.

7.2 Collaboration in networks

The management of collaborative activities includes both "soft" dimensions (human, organisational, etc.) and "hard" ones. Their integration of them in modelling and management is a challenge. The information technology has provided means to deal with these issues. Well known activities, like collaborative innovation, living labs and similar have become rather popular and they are supported by Internet solutions, such as cloud computing and service oriented architectures. However, the activities contain challenges, which are not easy to handle. One typical challenge is the management and protection of intellectual properties and privacy in collaborative networking environments.

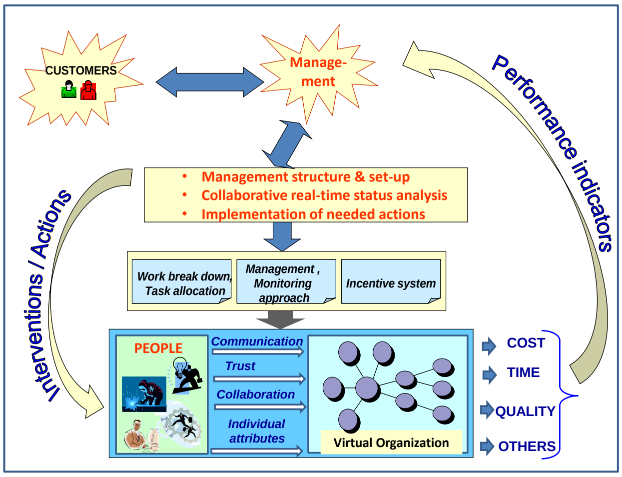

Fig. 6. Management of collaboration is about dealing with people.

In the collaborative networking area, research and development have so far mostly focussed on technical issues. Usually, the application of social media is considered as a solution for many needs in the area. Less attention has been devoted to the understanding and modelling of the processes. However, collaboration usually requires an atmosphere of trust, where many activities are performed by involved people, despite of risks and relying on incomplete information. Their communication and collaboration abilities impact on the performance, together with their mutual trust. The relationship between the issues is illustrated in the figure 6 /25/, which can be considered to be relevant for a large scope of networking activities. Independently of whether the activity aims at creating a physical product or some intangible intellectual output, the collaboration can, in many cases, be described as a “control loop”. The basic aim is to efficiently achieve the expected outcome. The performance indicators have to describe the efficiency of the networking process and the quality of the outcome. As the performance depends on the networking partners’ ability to collaborate and communicate and on their mutual trust, management activities and interventions should be devoted to these issues. Management impact is on intangible human assets. The main challenge is to relate these ones to tangible performance measures (cost, time, quality, etc.). Some kind of model is needed for the purpose.

7.3 Interoperability

Many of the activities described in this paper deal with some aspect of the interoperability. In technical systems, interoperability refers to the ability of systems to act together, to inter-operate. Hence, the focus is on the interfaces and their functionality. The advances in ICT, together with an increased use of digital automation solutions, have also increased the need of interoperability. Mostly, the focus has been on the technical exchange of information between systems (and sub-systems). During the years, several standards solving such problems have been created, representing the “final” solution for interoperability (CAMAC, MAP, Field-bus, EDI, XML, Rosettanet, etc.). In connection with the increasing networking, focus of interoperability has changed towards activities and collaboration in the networks. Software solutions and social networks seem to have taken the role of “solving” the interoperability problems. “Future Internet” and “Internet of Things” are also considered to provide bases for interoperability. The role of the new advances is important as they support the appearance of enhanced interoperability solutions.

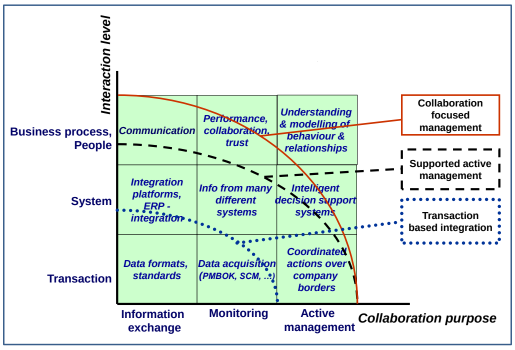

Fig. 7. Relationship between collaboration purposes and interaction levels.

The necessary basics for interoperability are the transfer and presentation of knowledge created and used in different environments. The challenge for interoperability relates to the expansion to a large scope of organisations, including e.g. social and legal activities. The model in the figure describes some aspects of interoperability /25/. Still today, the focus of collaboration is, in many cases, on the exchange of information and the interaction is transaction based. In figure 7, the collaboration level increases via (passive) monitoring towards active management. Integration increases from transactions via system integration towards the integration of people and business processes. A move from the lower left corner towards the upper right corner represents solutions for better collaboration and increased integration. Some descriptions of involved solutions are given in the figure. Especially, activities in the right upper corner still require development of models and means for understanding and modelling complicated relationships /25/.

7.4 Process vs product

The applications described in this paper are related to the management and control of processes. The objective has been to enhance the performance of the processes with respect to some expectations. However, most processes aim to produce some outcome, some kind of "product". The main measure of the process performance needs to be the quality of the outcome, how well it fulfils the expectations. If they are not fulfilled, other types of process efficiency are almost irrelevant. Naturally, there are strong relationships between the process and its outcome.

Products and their features could be increased be applying systems theory, and thus making them more attractive. Service products form a growing business area. The service product may be an independent product on the market or it may be attached to a physical product. Services can also be embedded into the physical product. This type of knowledge intensive products seems to become important in the future. To deal with them from a business point of view, new value propositions for immaterial products, like services, need to be developed.

We could extend the discussion about processes vs products to a more general level. In the present economic environment, the creation of new wealth has to rely on innovation and the development of new attractive products and services answering to needs on the markets. Cuttings and reductions of activities or enhancement of old processes cannot be a solution, especially if the produced products do not fulfil the expectations.

7.5 Research

This paper describes work performed in research environments. In research, the focus has to be on the research output, i.e. on the product. The product for a research organisation must be high quality research and development work. All other activities must support the achievement of this aim. Naturally, the research process differs from the production of physical products. For instance, marketing of research consists of discussions and agreements between highly specialised persons. Marketing organisations can here give very little contributions.

Research relies on collaboration with almost as many work habits as participants in the collaboration. Enthusiasm and commitment are the main drivers, which are necessary requirements for success. For the management of research, the main question is how to maintain and enhance these drivers. A trustful and free atmosphere seems to good means. Strict procedures and formal processes seem to reduce both commitment and enthusiasm, consequently also reducing the quality of the outcome. Naturally, infrastructure and support functions are necessary, but they should be subordinated to the research, not vice versa.

In creative organisations, knowledge is distributed to all levels. It is not only on the top, nor is it only at the grass root level. Efficient utilisation of the cumulative knowledge of the whole organisation is a big challenge, but also a key to success.

7.6 Knowledge

In well developed countries with fairly high cost structures, like in Finland, the success of the country must rely on deep real knowledge and the ability to use it in new and challenging, i.e. innovative, forms. Proclamations are not knowledge. Nor are unrealistic objectives without realistic connection to reality.

In the rapidly changing world of today, we have to especially build on knowledge, which remain. Basic principles and science are time invariant assets, even when the environment changes. Specific technologies and popular application come and disappear after some time. As we never know about the future, a wide knowledge base is a necessary condition for building the future, although it is not always a sufficient condition. Consequently, a good comprehensive all-round basic education seems to be preferable compared to narrow specialization, especially in a small country.

8 REFERENCES

/1/ Ollus, M.: Systems in Practice – Some Applications of Systems Theory, in Wahlström, Björn & Ollus, Martin (ed.): *Systeemiteoria ennen ja nyt - systeemit muuttuvassa maailmassa*, Aalto-yliopiston julkaisusarja, TIEDE + TEKNOLOGIA 6 2014. ISBN 978-952-60-5670-8. Downloadable from: http://urn.fi/URN:ISBN:978-952-60-5669-2.

/2/ Ollus, M.: Professori Hans Blomberg: Suomen automaatiotutkimuksen ja –opetuksen kehittäjä, *Automaatiopäivät 2017*, Suomen Automaatioseura, 2017, Vaasa.

/3/ Ho, B. and Kalman, R.: Effective construction of linear state-variable models from input-output functions, *Regelungstechnik* 12: 545–548, 1965.

/4/ Kalman R. E., Falb P. E., Arbib M. A.: *Topics in Mathematical Systems Theory.* International series in pure and applied mathematics, 1969, New York, McGraw-Hill.

/5/ Åström K. J., Bohlin, T.: Numerical Identification of Linear Dynamic Systems from Normal Operating Records. In P. H. Hammond: *Theory of Self-Adaptive Control Systems* (pp. 96-111), Plenum Press, 1966.

/6/ Bohlin, T.: On the Maximum Likelihood Method of Identification. *IBM Journal of Research and Development*, Volume 14, Number 1, Page 41, 1970.

/7/ Korhonen, J.: Paperikoneen prosessinohjauksen alkuhämärä 1962 – 1966. *Teollisuusautomaation vuosikymmeniltä 1960- ja 1970-luvut,* Finnish Society of Automation, Publication 23, 2001, ISBN 952-5183-15-7.

/8/ Lee, R. C. K.: *Optimal estimation, identification, and control.* M.I.T. Press research monograph, 1964.

/9/ Vuorinen, A.: Loviisan ydinvoimalaitoksen instrumentointi. *Automaatiopäivät 1975*, Finnish Society of Automatic Control, 1975.

/10/ Haapanen, P., Winter, M.: Kokemuksia Loviisa I:n pääsäätöjärjestelmän suunnittelusta. *Automaatiopäivät 1975,* Finnish Society of Automatic Control, 1975.

/11/ Winter, M.: Ydinvoimalaitosten automaatio ja simulaattorit. *Teollisuusautomaation vuosikymmeniltä 1960- ja 1970-luvut*, Finnish Society of Automation, Publication 23, 2001, ISBN 952-5183-15-7.

/12/ Salminen P., Ollus M., Wahlström B., Winter M.: *Preliminary specifications for a training simulator for a PWR nuclear power plant*. Valtion teknillinen tutkimuskeskus, sähkötekniikan laboratorio, tiedonanto 5. 1974. ISBN 951-38-0094-6.

/13/ Heimburger, H., Ollus, M.: Simulaattorit prosessien henkilökunnan koulutuksessa. *Automaatiopäivät 1975*, Finnish Society of Automatic Control, 1975.

/14/ Mäenpää I., Malinen P., Ollus M., Saukkonen E., Wahlström B., Uotila E.: A Computer System for On-line Sorting Based on Visual Images. *Proceedings of the 6th International Conference on Automated Inspection and Product Control*, Birmingham, U.K. 27-29 April 1982, s 145-152. 1982.

/15/ Wahlström B., Juusela A., Ollus M., Närväinen P., Lehmus I., Lönnqvist P.: A Distributed Control System and its Application to a Board Mill. *Automatica*, vol 19, No 1, s. 1-14, 1983.

/16/ Ranta J., Koskinen K., Ollus M.; Flexible production automation and computer integrated manufacturing: recent trends in Finland. *Computers in Industry*, Vol. 11, pp. 53 – 76, 1988.

/17/ Ollus M., Lovio R., Mieskonen J., Vuorinen P., Karko J., Vuori ., Ylä-Anttila P.: *Joustava tuotanto ja verkostotalous - tekniikan, talouden ja yhteiskunnan vuorovaikutus 1990-luvulla.* SITRA 109, Helsinki, 1990.

/18/ Ollus, M., Ranta, J., Ylä-Anttila, P.: *Yritysverkostot – kilpailua tiedolla, nopeudella ja joustavuudella*. SITRA 201, Helsinki, 1998. ISBN 951-628-281-4.

/19/ Ollus, M., Ranta, J., Ylä-Anttila, P.: *Verkostojen Vallankumous – Miten johtaa verkostoyrotystä?* SITRA 202, Helsinki, 1999. ISBN 951-628-282-2.

/20/ Ranta J., Ollus M., Leppänen A.: Information technology and structural change in the paper and pulp industry. *Computers in Industry* Vol. 20, 255 - 269, 1992.

/21/ Karvonen L., van den Berg R., Bernus P., Fukuda Y., Hannus M., Hartel I., Vesterager J.: *Global Engineering and Manufacturing in Enterprise Networks. GLOBEMEN.* VTT Symposium 224, ISBN 951-38-5739-5; 951-38-6275-5, 2003.

/22/ Camarinha-Matos L., Afsarmanesh H., Loeh H., Sturm F., Ollus M.: A strategic roadmap for advanced virtual organizations. In *Collaborative Networked Organizations: A research Agenda for Emerging Business Models*, Kluwer Academic Publishers, 2004.

/23/ Camarinha-Matos L., Afsarmanesh H., Ollus M.: *Virtual Orgaizations – Systems and Practices*, Springer, 2005, ISBN 0-387-2355-0.

/24/ Camarinha-Matos L., Afsarmanesh H., Ollus M.: *Methods and Tools for Collaborative Networked Organizations*, Springer, 2008, ISBN 978-0-387-79424-2.

/25/ Ollus, M., Jansson, K., Karvonen, I., Uoti, M., Riikonen, H.: On Services for Collaborative Project Management. *Leveraging Knowledge for Innovation Collaborative Networks:10th IFIP WG 5.5 Working Conference on Virtual Enterprises, PRO-VE*, Thessaloniki, Springer 2009.