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My Way in Cybernetics - For 50 Years

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Abstract

Increased application of engineering cybernetics- and control engineering have been considerable since the late 1960s. The driving forces have been many, such as improvements/pioneering in defense and space technology, maritime- and oil production technology, robotics and industrial control, enabled by a huge increase in available computing power. I have been involved in this development for the last 50 years. This paper sums up my work within areas such as mathematical modelling for control and estimation, Kalman filtering, and the development of software, simulators and applications for such purposes. During these years I worked, as examples, within the fields of ocean modelling for real-time estimation, oil production, dynamic positioning and industrial control in the fields of fertilizers, and aluminum production. The stories of starting up the company Prediktor and the following development of Manufacturing Execution Systems (MES systems) and my engagement in the use of optical NIR based technology for industrial control in various industries are told. My hope is that the story might be of interest to younger engineers today to understand the development in this engineering cybernetics field for 50 years as exemplified by my career.

Keywords: Engineering cybernetics history, dynamic positioning, model based estimation and control, ocean modelling for estimation, applied control theory.

1 Introduction

I was born in 1946. Since I was a little boy, I always wondered about things I observed around me. This wondering has been with me ever since. This paper is about my life in the field of cybernetics and my constant desire of trying to understand how and why things work coupled with a drive to apply such knowledge for useful purposes. My curiosity as a child was probably a nuisance to my parents when I asked all kinds of questions about the working of things: "Why is this" and "Why is that".

All that curiosity led me into realizing many young boy experiments by making gun powder from ox-blood and coal, making toy rockets from bicycle pumps and making radios, electronic amplifiers and very small scale hydro power plants in a nearby run of water. To engage in such hobbies was not so different from what many other young boys at that time did, before the times of kindergarten and internet.

I grew up in Varteig, a small rural community of around 2500 people near the city of Sarpsborg, with which it was merged in 1992. The primary school I attended was small and the number of pupils was low, so we attended school every other day. Three days a week + Sunday, I had ample time for my free-time activities. At that time, I was convinced to not end up in an office, but to be a carpenter, an electrician, a mechanic or similar.

These plans changed when I entered high school in Sarpsborg city and found out that I needed further education to satisfy my scientific/engineering curiosity. At that time, I was reading books from the local library all the time. I remember a red-cover book of Einstein's relativity theory, a popular version written by Einstein himself in 1916. My physics teacher asked

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me if my father was a physicist. He was not. He was a road keeper. I think she asked because I often aired tricky questions and knew a lot about physics which she neither had talked about in class nor was it a part of the syllabus.

This formed my plans about being an engineer. To enter the NTH study, I needed very good grades. I was not that super in the French language, in history etc. (I liked German because of the predictable grammar), so my backup plan was to be a meteorologist if I failed to enter NTH. But I succeeded, after not so joyful extra efforts in my not so favorite subjects. I entered NTH (now NTNU) as an electrical engineering student in 1966.

At that time, a year of manual and relevant work was needed before entering the study, so I worked for one year at Richard Pfeiffer AS (summer 1965 to summer 1966). Pfeiffer was a Sarpsborg based plant producing electrical transformers in all sizes and also did maintenance work on those as well as large electric generators and motors. This, I thought then, was a waste of time. In hindsight I am very glad that I was forced to do this. I learned a lot about technology and how a technology plant and the social network at the factory was functioning.

2 A Student at NTH (1966 – 1973)

Settled in Trondheim in the autumn 1966, I could start learning real engineering and trying to understand how things worked around me full time. That turned out to be my way of professional life from that time till now, over a period of more than 50 years.

At that time all the students in electrical engineering started out either in the direction of power engineering or at the "svakstrøm" ("weak current" in English) direction, meaning all the rest covering electronics, radio engineering, telecommunications, acoustics and engineering cybernetics. After the first two general years you had to select one of these directions.

My initial decision was to be a radio engineer, but then, I met Professor Jens Glad Balchen. He was an extremely inspiring teacher in control engineering. Balchen was the person who founded university studies in this field in Norway. He told us that almost anything could be modelled mathematically at some level, from a chemical reactor to a ship or a rocket headed for the moon or human happiness (someone made a report on that). I found that intriguing and wanted to learn more about this. So, I switched my main theme selection from radio engineering to control engineering. I never regretted that.

In my class at NTNU we were 39 young men and no women studying control engineering in the late 1960's. I guess many of us selected that direction due to Jens Balchen's extremely interesting lectures in basic control engineering. Most of us didn't know anything about this subject on entering NTH. And I think most of us were fascinated by the everywhere presence of feedback and control in all kinds of systems around us.

One of my first really nice experiences as a Balchen student was to program a simulator on the 42 Kbyte memory GIER-computer in the Algol 60 language for simulation of launching a rocket and make it travel to the moon. The simulation of the journey and the control of the rocket engines took a few hours of CPU time on the GIER machine. By the way, that GIER computer was the second one in Norway. The first one was bought by the Institute for Nuclear Energy in Halden (later named IFE).

In 1968, while still a student, I bought a book by Norbert Wiener on Cybernetics (see Wiener (2019)). That was a hugely inspiring book, even though I did not understand everything in it at that time. A little comment about Norbert Wiener is that he visited Balchen and his department in 1964 in Trondheim. Balchen had a huge network, including him. Sadly, Wiener actually died on his way home from that meeting of a heart attack.

Jens Balchen, Ole Solheim and Odd Pettersen were teaching us about computers, instrumentation and control, including "modern control theory" such as Kalman Filtering, optimal control and Pontryagin's maximum principle, as well as the classic control theory. Balchen was the strong man with ideas popping out of him all the time. Odd Pettersen was the archetypical lab engineer (later professor), wearing a white lab-coat. Ole Solheim was a very nice person teaching me a lot of things and also formulating the theme of my Master thesis. Unfortunately, he died much too early in 1989.

2.1 Master

My master thesis work was initiated and supervised by Ole A. Solheim and was about parameter sensitivity in optimal control systems. Solheim had observed, by using the Balchen-designed Diana analog computer, that high gain feedback systems might be extremely sensitive to feedback coefficient perturbations. So, my work was about finding out why. I analyzed this mathematically and Solheim and I published a conference paper on the results in 1971, Solheim and Sælid (1971).

Sometimes the work was a little frustrating. I used the central UNIVAC 1108 computer, and I punched in my Fortran code in a stack of cards on a card punching machine. One card represented one line of code. This pile of cards was delivered at the computing center for running on the UNIVAC. That unfortunately took some time, and I was lucky if I could run my program twice a day. So, the debugging was time consuming. I think I used a week to find out that the Fortran library for linear algebra I used, failed when trying to invert a one-dimensional matrix (a scalar)!

2.2 PhD work - Rotary Cement Kiln Control

Having finished my master, I started as a research assistant at the Department of Engineering Cybernetics and Jens Balchen was my boss. He had contacts in the cement production industry in Norway (Norcem). Norcem in Brevik experienced stability problems as amplitude temperature oscillations on their largest rotary cement kiln. I started trying to find out why and how to improve this as the theme of my PhD work.

I first made a rotary kiln simulation model based on mass- and energy balances and modelling of the chemical reactions going on. I soon had a quite detailed simulation model, written in Fortran on a NORD-10 computer from Norsk Data. I made a simplified model and tested out optimal control algorithms by simulations and estimation based on an Extended Kalman filter and a reduced order nonlinear model.

The problem was that I was unable to reproduce the observed instabilities. The simulated control worked perfectly. So, I went back to the modelling and analyzed the rotary kiln operation. I discovered that on maximum production, the CO2 gas generated in the first part of the kiln was large enough to produce fluidization of the powder feed material in that first part of the kiln, so that the fluidization made the raw material powder behave like a fluid that was flowing into the hot calcination zone and thus was killing the exothermic chemical reactions going on there. This probably started off the observed instability with a 1-2-hour period. The oscillations were probably not a control problem, but a process design problem (Sælid (1976a) and Sælid (1976b)).

I learned a lot about modelling, Kalman Filtering and optimal control from this work, but the most valuable experience was to learn about the close coupling between process design and control.

3 Years at Sintef and NTH (1974 – 1982)

Sintef and NTH were symbiotic and very close at that time; both research-wise and by occupying the same office spaces. When switching from NTH to Sintef, I didn't switch office space. I had two bosses: Prof. Balchen at NTH and Head of department Knut Grimnes at Sintef.

Norcontrol was a very attractive place to work at that time. Many of my colleagues started there. Tore Endresen at Norcontrol was maybe the first in Norway to realize an industrial Kalman filter. That was for a ships navigation and anti-collision system. Norcontrol was a place where young control engineers could play with computer control on the maritime arena. I got a job offer from Norcontrol but started at Sintef which offered me interesting work as well and even better pay than at Norcontrol.

Jumping forward in time: A strange situation appeared many years later in 2009. Tore Endresen had been dead for many years, and Kongsberg Maritime, who had acquired Norcontrol, needed to upgrade the Kalman filter in the ship-radar-tracking system. They received some simulated test cases from the approval authorities, and the system did not pass. Nobody was acquainted with this Kalman filter code anymore, so Prediktor (where I worked) was given the task (Oddvar Grønning and me) to look into the code and translate it to C++ and improve it if required. We found out that the reason for the no-pass tests was an error in the test data. So, the software written by Tore Endresen actually worked perfectly.

After my time in Sintef, I observed the start of Sintef and NTNU drifting somewhat apart. Jens Balchen and people in industry were frustrated because Sintef was seen to compete with tasks that naturally belonged to the industrial sphere.

3.1 Antenna dynamics

My first Sintef project was a small one. I worked for a few weeks on it but increased my interest and professional focus towards process design and process dynamics interaction. The project was about making a simulator for a gyro stabilized ships satellite antenna for finding out how the design parameters (gyro wheel size and speed, gimbal support position relative to the center of gravity, damping parameters etc.) influenced the antenna response on vessel motion.

3.2 Multivariable control of a fluidized bed reactor

A major project for me was about multivariable control of a fluidized bed reactor for roasting of pyrite. This was a research project, and the purpose of it was to test model-based control or "modern control" for metallurgy processes. A lab reactor at the NTH metallurgy department lab was the test process. A drawing of the process from Sælid et al. (1979) is shown in Figure 1.

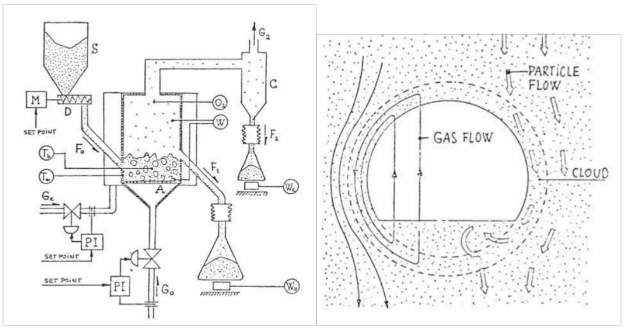

Figure 1: *Fluidized bed reactor with instrumentation (left) and flow around an air bubble*

The purpose of the process was to remove sulfur from fine-grained pyrite particles to produce Fe_3O_2. The reaction is strongly exothermic, so reactor cooling is required.

A reduced order model for the process was identified, based on physics and chemistry and parameters were identified by experiments. A model-based control system was realized and shown to work very nicely on this multivariable system.

The project went on for more than a year and Tor Lindstad made a PhD out of it. Leiv Kolbeinsen and Tor Onshus also participated in the project, and both became professors at NTH/NTNU later (in metallurgy and instrumentation respectively).

One day in the project during our experiments, something special happened. The computer control was executed by a NORD-10 computer located at the Department of Engineering Cybernetics via cabling running more than a hundred meters in underground ducts at the campus to the metallurgy lab location. A researcher at the cybernetics computer lab did not realize that real-time control was actually going on. He swapped our connection for his own with dramatic results. All valves controlling our roasting process went full open and lava-like red-hot pyrite geysers came out everywhere. Fortunately, no one was injured, but we all learned a lesson about the necessity of fail-to-safe-design of processes and control equipment.

3.3 Ocean Modelling – Havbiomodeller

Another, even bigger project at that time was the Havbiomodeller project (in Norwegian) initiated by Jens Balchen. The idea was to model the entire physical and biological dynamics of the Barents Sea for optimizing the cod fish production- and harvesting plans. My task in the project was to model the oceanography of the Barents Sea including flows, temperatures and salinity. Figure 2 shows the author running a simulator on a NORD-50 computer showing sea level contours of the Barents Sea on the screen. The simulations were challenging, and we had to find clever methods for speeding up the simulations Berntsen et al. (1981).

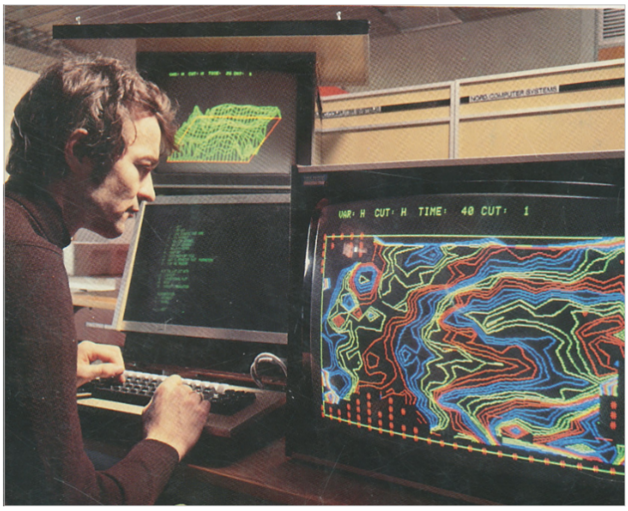

Figure 2: *Me running a Barents Sea simulation program*

As part of working with the Havbiomodeller project and making a model of the Barents Sea oceanography for estimation and prediction, I spent a year as a visiting scholar at the University of California in Los Angeles (UCLA) in 1977. My mentor there was Professor Cornelius Leondes at the Systems Engineering Department. He was very busy with many things as a newly appointed advisor to President Carter, but he was helpful when present.

During that time, I established contacts with, and visited, several control engineering, meteorology and oceanography research institutions such as the Fleet Meteorology and Oceanography Center in Monterey, University of Washington in Seattle, UCSD in San Diego and UCSB in Santa Barbara. I also got in contact with the Rand Corporation in Santa Monica who did work on ocean modelling. Being at UCLA I worked with numerical simulation and estimation of sea states. That resulted in the biggest Kalman Filter I have ever worked with. I wrote a paper based on this about observability in such systems Sælid (1978). I learned a lot about numerical simulation of weather- and ocean systems during my stay there, and I was introduced to the term "4-dimensional data assimilation". The meaning of the 4th dimension is time and data assimilation was almost the same as Kalman filtering. It is interesting to note that Kalman filtering is routinely used in meteorological forecasting today.

The results from the project did not find immediate applications. The ideas were extremely radical, and parts of the research establishment named Balchen as a person with somewhat to ambitious ideas at times. However, the fact is that downstream the Havbiomodeller efforts, the ideas are living on. An example is reference Wassmann et al. (2006). Dag Slagstad was an important contributor to the Havbiomodeller working on plankton dynamics and the ocean-fish interaction.

A story about Jens Balchen in the middle of the Havbiomodeller project tells about his personality and drive for his ideas. Balchen and a few of us had a meeting in Bergen with the oceanographic- and the fisheries research professors and managers. Several of the Bergen people raised questions about the project feasibility. They told us that this was difficult. Jens told them that they did not understand anything and even named one of the professors a “pappskalle” in Norwegian. This translates to something like “a head made of cardboard pulp” in English. On waiting for a taxi outside, I hinted that it potentially was better to exercise some diplomacy. Jens looked at me and said: “Steinar, you never get anywhere in this world without stepping on somebodies toes!”

3.4 Dynamic Positioning

My mentor, Jens Balchen, had a sabbatical year in California in 1967/1968 at the University of California Santa Barbara. There he got the idea that optimal control methods and Kalman Filtering theory, heavily used in space technology, might be perfect for dynamic positioning (DP) of ships and oil platforms engaged in drilling, or oil production support activity. A DP system coordinates thrusters- and propeller response for keeping the vessel in a fixed position or to get a vessel to travel along a determined route (for e.g., pipe laying).

Coming back to Norway he started up a series of master students and activities to prepare this for use in the new North Sea oil industry. In the early seventies he obtained attention for this idea from Kongsberg Våpenfabrikk (KV – now Kongsberg). He got money from KV for a project, and Nils Albert Jenssen and I were both engaged to execute it.

From 1973 the two of us occupied the same office at NTH and worked closely together on this project for several years in that office. The result was hugely successful. KV managed to sell the idea for this advanced DP system and started out what later became Kongsberg Maritime after Bjørn Barth Jacobsen managed to sell the idea to Stolt Nielsen Group. At that time Kongsberg Oil division owned the project. That division was headed by Rolf Qvenild (later KV CEO), who approved the project. The first vessel (Seaway Eagle) was operating on dynamic positioning in the North Sea in May 1977.

The modelling of the vessel behavior and its response to wind currents and hydrodynamic interactions and the use of this for control worked very well. Soon KV became world leader in the field and 80-90% of all dynamic positioning systems worldwide presently and historically are made by Kongsberg Maritime. The DP system was elected by Norwegian technical press as Norway’s greatest engineering achievement since World War II.

3.5 Autopilots and other spinoffs of the DP Project

A spin-off of the dynamic positioning work was the development of an adaptive auto pilot. This was a project I did for Robertson Radio. They made autopilots for commercial vessels and the project idea was to make algorithms that adapted themselves to the vessel and the weather conditions as well as to filter out rapid water-wave induced heading oscillations which the autopilot could not handle anyway. The algorithm was tested out at the Norwegian Coastal Express vessel Midnatsol and turned out to work well. See Sælid et al. (1984) and Sælid and Jenssen (1983). To obtain a fast and reliable response, a new method using a variable forgetting factor for parameter adaptation was developed by Kjell Kristoffersen and myself, Sælid and Foss (1983). To optimize the maneuvers for initial parameter estimation, I also did some work together with Kjell Kristoffersen as documented in Kristoffersen and Sælid (1980), where we used a Fisher Information Matrix based optimization method for optimization of parameter identification maneuvers. Robertson Radio was later acquired by Kongsberg Maritime, and I continued at KM to integrate the algorithm into the Kongsberg system.

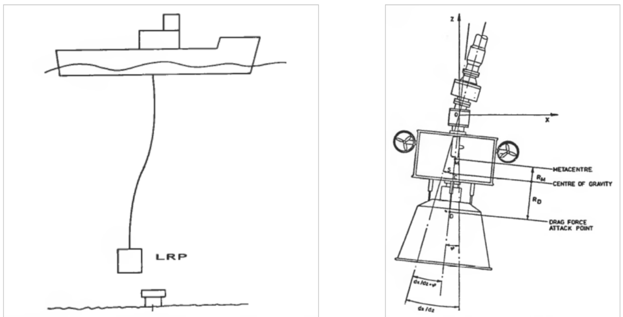

Figure 3: *Proposed system for offshore oil loading via a flexible riser by connecting a thruster assisted dynamically positioned connector (LRP) to the sea bottom well connection (left). Details of the LRP-connector to the right*

Another spin-off was about dynamic positioning of the end of a flexible riser for connection to an offshore bottom well assembly. The system was never realized because other solutions for offshore oil loading based on buoys and dynamic positioned loading ships was winning the game but Kongsberg Engineering (a part of KV) planned for such a system. This was in 1978.

The proposed positioning system was designed and simulated using models of the vessel, water waves, water current and the flexible riser dynamics, Sælid and Foss (1983). An adaptive Kalman filter and an optimal controller was compared to a PID based solution. The optimal controller solution was found to be superior. The riser modelling introduced was used later when I worked in Prediktor and made some consulting work for Kongsberg Maritime. The purpose then was to see if riser angle measurements at the top and bottom of a 1500-meter-long riser could be used as one of the required three independent position measurements for a drilling rig.

A 26th order Extended Kalman filter turned out to do the work and this was approved for use as a separate position measurement system during drilling operations, Sælid (1985a).

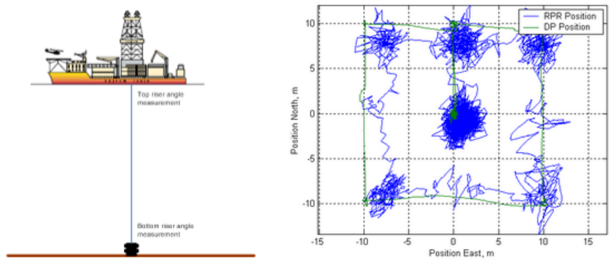

Figure 4: *Riser angle based position estimation. Estimation from the riser based estimator compared to the other DP position estimate to the right*

All this early activity in the 1970-ties and a little later actually was the start of a significant and long lasting activity in the field of ship motion control at NTNU: This activity has been dominated by professors Thor Inge Fossen (PhD in 1987) and Tor Arne Johansen (PhD 1994) at the Department of Engineering Cybernetics and professor Asgeir Sørensen (PhD 1993) at the Department of Marine Technology.

3.6 Educational Activities

My teaching at NTH/NTNU in my time as an associate professor (5 years), and later as an adjunct professor for 26 more years, has been within modelling, estimation, identification and model based predictive control (MPC). The adjunct professor activities were often related to my later industrial work via close to 100 master students and some PhD students. Some publications related to the latter are listed as references Rahmanpour et al. (2017), Staal et al. (2018), Staal et al. (2019a), Staal et al. (2019b). A quite special educational activity in the late seventies was related to the hunger for instrumentation engineering knowledge in the North Sea oil industry. So, the NTH continuing education department decided to make a course in instrumentation targeted to the oil industry. Ivar Loe from Norsk Hydro and I were asked to make the course, which we did. The unusual thing was that the courses were massively overbooked. We got a huge number of applicants but could not invite more than around 80.

4 Kongsberg Maritime (1982 – 1988)

Nils Albert Jenssen moved to Kongsberg first of the two of us following up the DP success there. The DP unit was first organized as a project and later as a KV company named Albatross after the first DP product name. I was still engaged in the DP system at Sintef and NTH, but some of my time went into the Havbiomodeller project and in 1978 I was appointed associate professor at the engineering cybernetics department.

At that time, I was thinking a lot of all the new distributed process control systems from Honeywell, Foxboro, Siemens and others. They were all different. Tor Onshus and I got an idea of making a simulator to emulate all of these distributed process control systems for educational purposes.

We applied to the Norwegian Research Council for money to examine this idea and we were lucky to be funded. We made a prototype, and we got the next idea that this might be a product in itself. A next generation distributed process control system (DCS).

I called my friends at Albatross and asked if they could hire me, and so I settled down in Kongsberg in 1982. The background for that decision was to be closer to the DP system activities and to get the opportunities to realize my ideas of making the mentioned new type of DCS system. In addition, I was a little tired of the, not always neutral, discussions of new professor specifications on the Faculty board.

My first time in Kongsberg was related to further refinement and development of the DP systems, including making a simulator for a pipe laying process and see if inertial navigation sensors might be of use in a DP system. The answer to the latter was no. But the idea of a new type of distributed control system was in the back of my head all the time. At Albatross, the idea for a new computer for use in the dynamic positioning system was born. The father of this single board computer idea was an extremely talented young engineer (everybody were young at Albatross – nobody was older than thirty something), named Vidar Solli.

After some time, the new single board computer was a reality. This computer had some revolutionary features. It was small and had Ethernet based redundant communication channels for multi computer applications, Bjørnstad (2009). Traditional thinking at the time was that Ethernet was not usable for process control due to its stochastic behavior. We argued, based of some calculations, that the probability of not delivering a message in time, via Ethernet, was considerably less than the event of a lightning hitting the computer if the traffic was restricted to very feasible intensities. Later, this has been an industry standard for process control applications.

The birth of this computer amplified my ideas for a new type of distributed process control system. This would fit perfectly into such a system. I managed to persuade the Albatross director, Nils Willy Gulhaugen, to allow me to start the project.

4.1 The AIM System

The rationale for Kongsberg Albatross to start the development of a new DCS system was the need for a general process control system to work with the DP system for energy management, engine control, ballast control and other related functionalities onboard a vessel or a rig. Albatross personnel was occupied with deliveries and further development of the DP systems, so we engaged Sintef and NTH for help in developing the system. We named the system AIM (Albatross Integrated Multifunction system). In the first two years of the development up to 5 persons in Trondheim were engaged: Sverre Gotaas (later CTO in KM), Professor Tor Onshus at NTH, researchers Harald Backer, Berit Floor Lund and Hans Berntsen at Sintef.

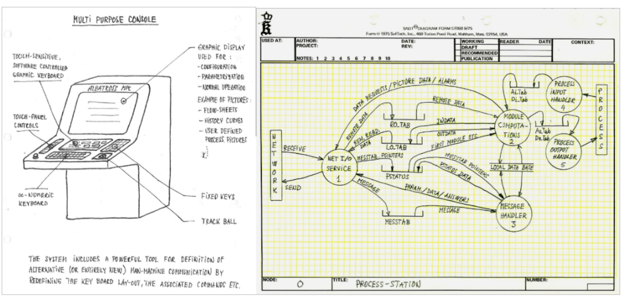

Figure 5: *Initial AIM console drawing (left) and Data store/flow diagram made by the author*

The architectural ideas behind the system were a complete object-oriented design, where functional objects could be configured to work in concert when doing control. Several computers could work together which made the system extremely scalable. Intercommunication between the computers were hidden from the user and all configuration was done by drawing P&ID like drawings graphically on the computer screen. The design ideas and the data flow and a hand drawn storage design are indicated in Figure 5.

In addition, AIM had a quite special functionality not to be found in any other process control system at that time. Simulation modules for the process units to be controlled could be programmed and integrated into the AIM system. AIM could then be put in simulation mode or in real control mode. In simulation mode, the control system could be tested against synthetic IO signals, generated by the simulation part, entering the control system as during real control. This made debugging and commissioning of the system far easier than for most other systems. In addition, operators could be trained by working in a simulated environment, Sælid (1985b). And the users liked it extremely well.

This dual use, as a simulator and as a control system played a trick on us during the commissioning of a system for controlling a batch distillation plant. We were thinking that the system was in simulation mode and thought that we were starting up a simulation when we heard the motors and the pumps starting to hum on the plant floor. The system was actually in control mode. After that we programmed a lock into the system making this impossible to happen by accident.

4.2 Norsk Leca

A working prototype of AIM was ready in 1986, and the sales team started the marketing. The first system was sold to Norsk Leca for control of a Leca clinker production plant. The system went operative in 1987 and included several distributed control computers communicating via the redundant Ethernet based system. A picture from the quite intense commissioning period is shown in Figure 6.

4.3 Saipem

Scarabeo 5 was a Saipem owned drilling rig to be equipped with both a DP system as well as an AIM system from Albatross. The AIM system had 50 single board computers for general rig control.

The rig was kept in position by eight Rolls-Royce anchor winches and eight Kamewa Azimuth Thrusters. This project was a success and the start of a series of AIM deliveries. Kongsberg has delivered a huge amount of such systems during more than 35 years.

Figure 6: *AIM installation/commissioning at Norsk Leca. From left: Gorm Johansen, Terje Løkling, Even Askestad (background), me and Ola Tjelmeland in red shirt (Norsk Leca)*

Figure 7: *The Scarabeo 5 drilling rig*

The last one is for control of the Johan Sverdrup platforms operated by Equinor in the North Sea. One very successful area for AIM systems delivery is for LNG ships control systems, where hundreds of systems have been delivered. In total KM has delivered AIM systems for billions of NOKs during the years.

5 Norsk Hydro (1988 – 2002)

After my happy Kongsberg times I started to work at the Norsk Hydro research center in Porsgrunn. It was sad to leave the company, but the AIM deliveries started to look like routine, and I was looking for new challenges. My job at Norsk Hydro was to participate in building up a group of people dedicated to advanced process control. That also turned out to be a professionally happy time. Norsk Hydro was then a conglomerate operating a lot of types of processes such as oil&gas-, petrochemicals-, fertilizers-, aluminum- and magnesium production. This was a heaven for a process control engineer. The research director at that time, Alf Bjørset (the later REC and Scatec founder), and other people in Norsk Hydro gave me freedom to think and try out new things.

5.1 Fertilizer production

One important area since the beginning of Norsk Hydro has been fertilizer production. One early challenge for me and colleagues in Norsk Hydro related to reducing environmental pollution from such plants. It was decided to make an operator support system for potentially fast identification of polluting incidents in real time and automatically find the root cause(s) for that. As a central part of the system we developed, was a plant model where each process unit were represented as an attributed object and the process flows between these were modelled as relations between the process objects. For each such relations/connection, several measured or calculated process variables were monitored for deviations. Once a deviation was detected by the system, the process object model, connected at the input of the process connection, where the deviation was detected, checked all incoming streams to see if the upset might have been caused by an upstream process object. If so, control was passed to the diagnoser associated with the upstream process unit, which in turn might pass control to a unit further upstream. This went on until a diagnoser did not find any relevant deviations in any of its upstream units. The diagnoser then decided that the cause of the upset was the current process object, and an internal diagnosis of this process object was initiated. This technology was at the time named as an expert system, which might be classified as a type of artificial intelligence.

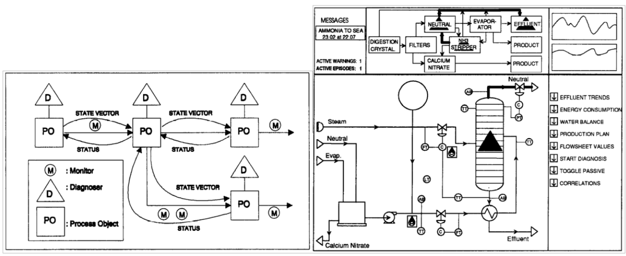

Figure 8: *Diagnostic principle (left) and one of the screens for the diagnostic user interface*

This diagnostic process could be controlled or overridden by the operator. The operator interaction was based on animated and maneuverable process flowsheet pictures where the diagnostic search was indicated by color coded process object and process connections between the detection place and the root cause unit. Figure 8 shows a sketch the diagnostic principle and one of the user screens where the triangle indicates the identified pollution source.

Norsk Hydro received an award from the Norwegian Ministry of Climate and Environment for the resulting pollution reductions. Another fertilizer related process I worked with was the ammonia reactor at the Norsk Hydro fertilizer plant in Brunsbüttel, Germany. The ammonia reactor is a large vertical tubular reactor filled with catalyst material where strong instabilities was observed from time to time. The instabilities were easy to reproduce by simulations, and this was solved by first simulating a modified control method and then trying out this on the real reactor. John Morud later worked on this and made a PhD where this was a part of that, Morud and Skogestad (1998).

5.2 Other Processes I worked with in Norsk Hydro

One other activity was about modelling, estimation and control of aluminum smelters. It is difficult to observe what is going on inside those furnaces and the process dynamics is tricky and characterized by the interaction between the material- and energy balance and the solidification/melting of the cryolite insulation layer at the smelter walls. I guess that was a start of an activity that continued after I left Norsk Hydro.

Other work I did at Norsk Hydro was related to magnesium production and to nitric acid production (for fertilizer production). The work in magnesium production was related to identification of bottlenecks in the magnesium chloride production and modify control/operation for improving this. It turned out that a process step early in the process determined the possible throughput in the real bottleneck much later in the process flow. This was preliminary work related to plans for building a new Hydro magnesium plant in Canada. These plans were later abandoned due to increasing Chinese production and competition.

Part of a nitric acid production study included realization of a process- and control system simulation of the plant. As a tool for doing this, I got a permission from Kongsberg to use the AIM system for making the process- and control system simulator, which I did. Based on the simulator I started to play with the idea to make a product for a combined control- and process simulator. That was the starting point for the CADAS project, which again was the basis for starting my own company, Steinar Sælid AS.

6 Steinar Sælid AS (1993 -)

In 1993 I established my own company based on the idea to realize the CADAS (acronym for Computer Aided Design and Simulation) project. An application to the Norwegian Research Council for CADAS was planned jointly with Norsk Hydro, Kongsberg Maritime, Aker, Kvaerner and Steinar Sælid AS. The project was awarded money and CADAS was developed. CADAS was technically a success but did not reach the commercial product stage as a product due to changes in the Kongsberg company, kicked off by buying the Norcontrol company. Norcontrol had their own simulator product developed together with IFE. But pieces of CADAS and associated ideas was used in an updated new simulator based on this. So, the Norcontrol solution was merged with AIM and parts of CADAS and lives on in a Kongsberg simulator product now maintained, developed and sold by Kongsberg Digital under names like Kognitwin categorized as a dynamic digital twin and K-Sim for training and educational purposes.

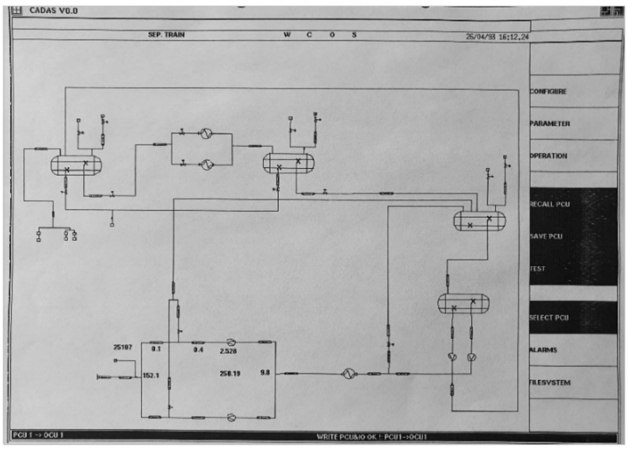

Figure 9: *Oil separation train simulated in a very early CADAS version*

In the middle of doing all this, I was contacted by Helge Mordt and Rune Storkås. They asked if I was interested in joining them in establishing a new company. I already knew Helge and all of us had our own one-person companies. We started up Prediktor in Fredrikstad in 1995.

7 Prediktor (1995 – now)

Prediktor was founded with the three of us plus Odd Arild Olsen (Odd Arild soon left the company) and my wife Vigdis as a secretary. The idea was to make money by selling our services and use the profit to develop software products for production operation support, control, optimization and reporting. Our previous employers and connections (Norsk Hydro, Aker, Elkem, Kongsberg, Kvaerner, Borregaard, Norcontrol, Norsk Leca, Valmarine) became our first customers.

Over the years Prediktor was growing. Currently (in 2023) Prediktor employs around 50 people. At the times, before the solar business entered into problems due to Chinese over-establishment, Prediktor had more than 80 employees. I was the CEO of Prediktor for 17 years until 2012 when Espen Krogh, who was the CTO at that time, and I switched roles. I was 66 years old at that time. All the time, my work was strongly technically oriented.

So, to the projects: One of the first projects was for Norsk Hydro. This project was about making an optimization- and operator support system for a fertilizer prilling process. The prilling was done by making pellets in a big tower by spraying hot fertilizer fluid from a top nozzle arrangement. The operator support system was named PRILLOP (acronym for Prilling Optimization). This was in the mid 1990-ties, and we were maybe the first, at least in Norway, to use web technology for this type of user interface realization. PRILLOP was also awarded an internal quality improvement prize in Norsk Hydro in 1999.

One other important project at this early time in Prediktor was the improvement of a control system for a Borregaard chlor-alkali plant. We solved a nasty control problem that tended to shut down the plant once or twice a week. That meant lost profit. The Orkla chairman of the board, Jens P. Heyerdahl (Orkla owned Borregaard at that time), was on the phone to Borregaard people to ask how things went once a week, I was told. Our solution to this came up based on a simulation study of the plant. The solution was simple and was realized in the plant's Honeywell control system in an hour or less, but it was a little tricky to find out how to do it. It worked perfectly, and everybody smiled; and the plant made money again.

Other projects we did at that time was making a CADAS simulator for the oil production Njård platform (Aker) to see if the platform control systems would work, a project for making an ice beer production control system for Borg Bryggeri, to make an operation support simulator for ferrosilicon production (RAFSIM) for Elkem and to make a model based control system (MPC) for Norsk Hydro (PVC powder production).

7.1 BISP – The birth of APIS and ModFrame

We (in Prediktor) realized that many of the things we did for customers at that time might be made into generalized products. We agreed with some of our customers to plan for a project doing this and then applied to the Norwegian Research Council for funding of it. The result was the BISP project for developing these ideas. Translated from Norwegian, BISP was an acronym for Decision-, Information- and Control support for the Process industry (Beslutnings-, Informasjons- og Styringsstøtte system for Prosessindustrien in Norwegian). We got the funding. Three years and 25 mill NOK later, the basis for new Prediktor products was ready.

7.2 APIS – the real time platform

This was one of the main products resulting from the BISP project: A platform for connecting real-time software products in a well-defined way. The APIS platform was Windows based and included software modules for connecting to process equipment. The interface modules were named APIS Bees. APIS was named after Apis mellifera which is the name of the European honeybee. APIS also consisted of supporting applications for control and/or reporting. Rune Storkås and Espen Krogh were the main architects and programmers for the APIS system. The APIS structure is shown in Figure 10. APIS Hive is the real-time data store and data exchange part and APIS HoneyStore is a historical time series- and events database.

7.3 ModFrame

The basis for ModFrame was also developed in the BISP project. The name is an abbreviation for Modelling Framework. ModFrame could connect to APIS as seen in Figure 10 and has a configuration interface where modules can be selected from a menu and configured and connected graphically as shown in Figure 11. The modules are created according to a defined interface and a defined set of methods to apply to each module, such as RunTimestep, GetParameters, ChangeParameter etc. Modules for simple logic-, statistical- and arithmetic calculations, linear algebra as well as complicated modules for simulation and advanced control such as Kalman Filters and MPC were developed.

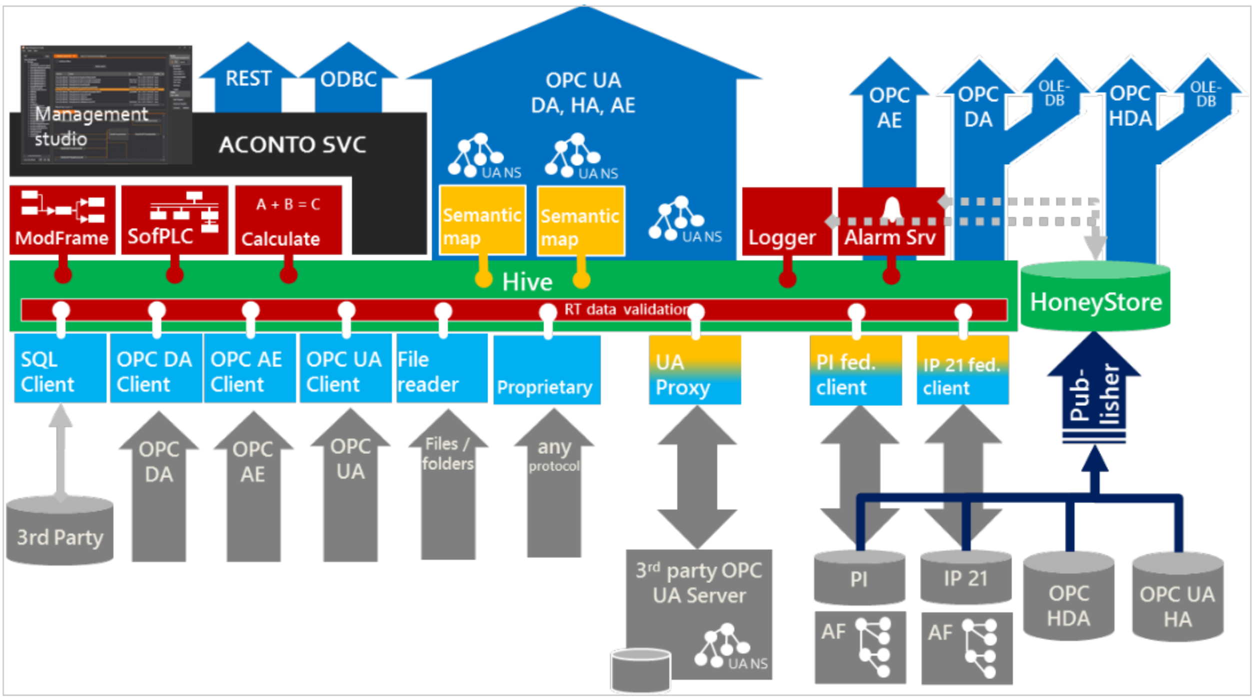

Figure 10: *APIS module structure*

ModFrame has been- and is extensively used for process logics and other calculations as well as for rather complex simulators and controllers.

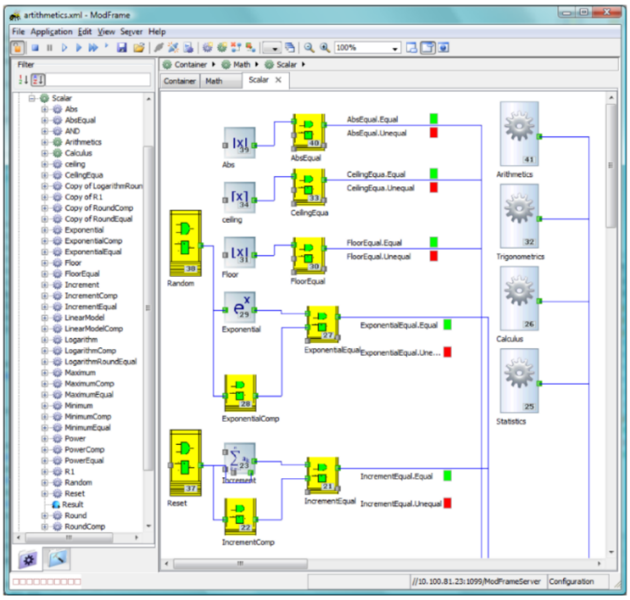

Figure 11: *ModFrame screenshot*

Examples of ModFrame use are:

- A CO_2 capture process simulator.
- A simulator for a fluid oxygen removal process (Minox).
- Subsea oil and gas production flow management (for FMC, now TechnipFMC).
- Kalman filtering and model based predictive control for the Ormen Lange gas production process.
- Paper machines model based predictive control and Kalman filtering (Norske Skog).
- Multivariate quality production control estimation for the food-and feed industry.
- Production mass- and product tracking (more on that later) for many industries.

Many of the features and architectural principle developed in my earlier AIM- and CADAS work were applied in the ModFrame design, see Sælid (1985b). APIS and ModFrame products has been installed in large numbers around the world.

During the first years in Prediktor we got a customer that was especially important in shaping Prediktor's future. That company was Silfas (now Pelagia). The company produced fish meal and fish oil from raw fish and needed a production supervisory and reporting system. Prediktor's system that we made for them tracked fish loads from delivery at the quay to finished products. A drawing created during a brainstorming

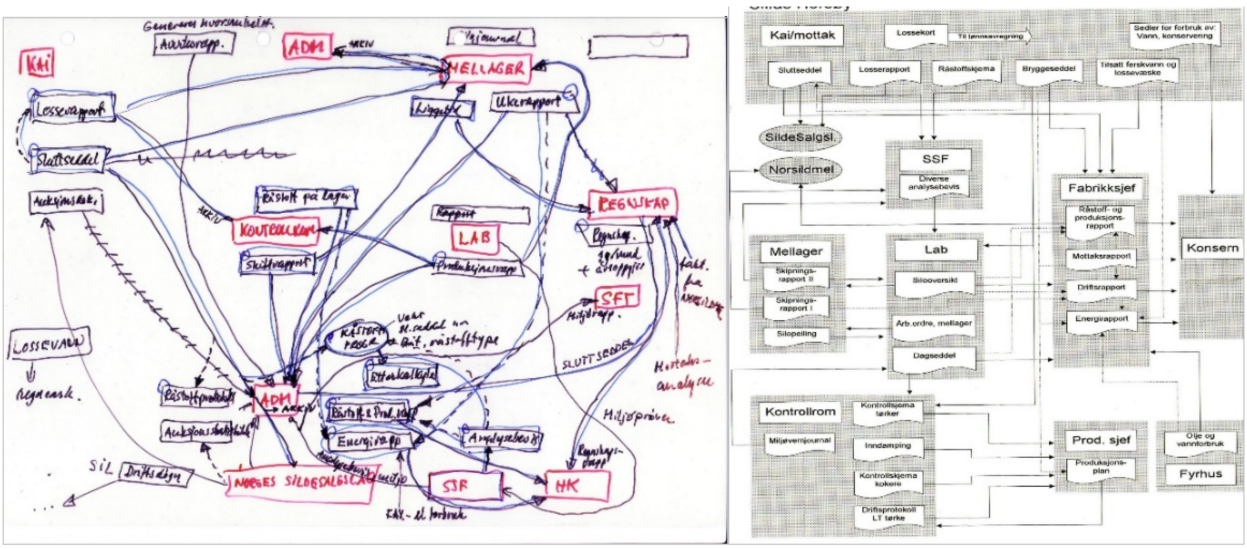

Figure 12: *Blackboard prework on part of the existing reporting structure to the left in 1997 and the resulting Prediktor system structure to the right*

session at Silfas Horsøy and a walk through of the existing reporting before the Prediktor system was created and installed is shown to the left and the resulting new reporting structure to the right in Figure 12.

The resulting reporting system contained many of the features of the production tracking MES systems that were delivered from Prediktor in the coming years. Figure 13 shows some typical user interface/reporting screen shots for this system. You could navigate from the left screen, via the middle one to the raw materials details screen to the right. This was done in the final 90-ties, and the use of web technology for user interfaces was not the norm at that time.

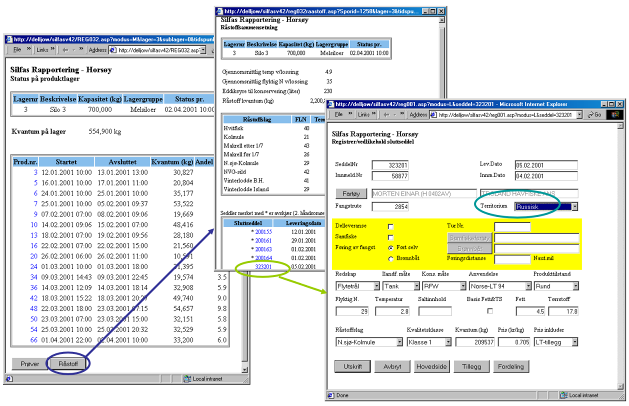

Figure 13: *Silfas system screenshot examples*

A little later, as a result of the BISP project, two other customers were acquired: Skretting (now Nutreco) and BioMar (now Marine Harvest). Prediktor was engaged to improve their fish feed production quality. This was done by tracking the production from raw materials to final fish feed products and registering the process parameters experienced by a defined mass plug while travelling through the production.

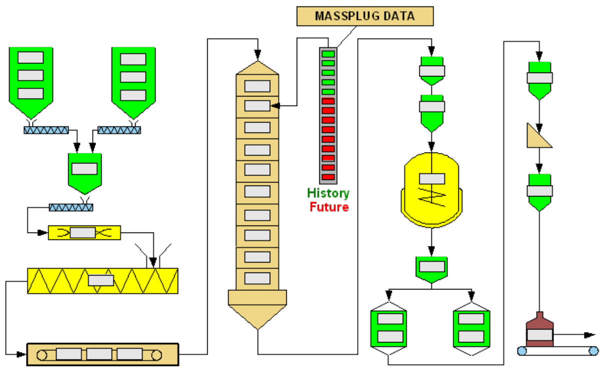

Figure 14: *Fish feed material tracking*

The data experienced from each mass plug was collected by using a real-time mass flow model and using process flow measurements and mass accumulation data to predict the position of each of the mass plugs. The collected data was then used to model the relationship between experienced process conditions, raw materials characterization and the resulting quality parameters. The principle of the tracking engine for mass plugs as well as a prediction of a quality parameter is shown in Figure 14. The gray squares illustrate mass plugs. These were virtual mass plugs created by the software by chopping up incoming material in decided sizes, such as one cubic meter. Figure 15 shows the model-predicted and post-production analysis of the resulting feed pellet moisture content of a few days of production. This model could then be used for adjusting production process set points for better quality control.

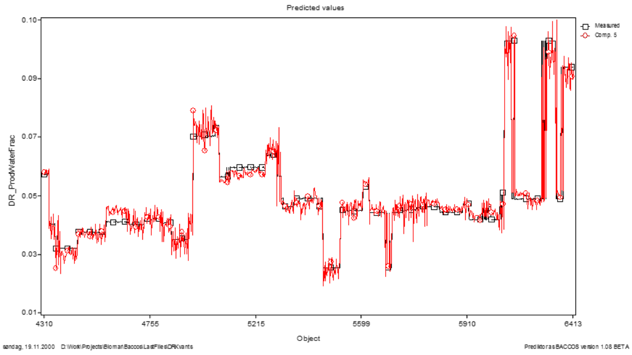

Figure 15: *Produced pellet moisture analysis (black) and predictions (red)*

7.4 MES systems

The systems made for Silfas and the fish feed industry was the basis for a new generation of systems, termed MES systems (Manufacturing Execution Systems, Wikipedia (2023)) for Prediktor. The experience from the mentioned deliveries was transformed into a new product named APIS Click&Trace. The system was based on production information models as defined in the S95 standard, Teknisk Ukeblad (2013). The first system based on this product was delivered to REC (Renewable Energy Corporation) in 2002 for operation support, management and reporting of solar wafer production. The Click&Trace system was installed at the REC plant (then named ScanWafer) at Herøya in Porsgrunn, and the production was tracked. The history of all wafers coming out of the system was registered and reported. The production tracking was based on a ModFrame production model. A small part of the tracker definition diagram for the REC wafer plant is shown in Figure 16.

REC was Prediktor's largest customer for many years and data from the Prediktor MES system was part of the huge production cost reduction and quality improvements in many REC plants during the years. As an example, the system made possible the identification of root causes for low quality wafers produced, such as a degradation on a specific wafer cutting saw or a gas leakage in one of the furnaces. This system for the solar industry was installed at many wafer plants, solar cell plants and solar module plants for REC and many other companies worldwide. The Prediktor Click&Trace system is installed in many other industries and types of production plants such as food pro-

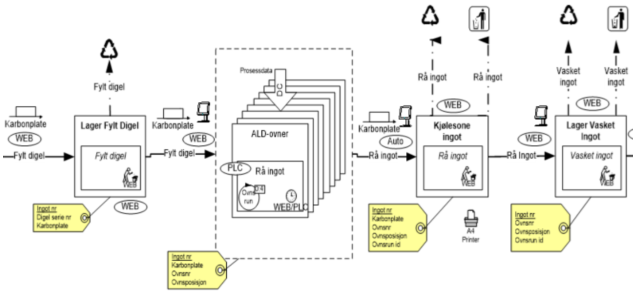

Figure 16: *A small part of the Click&Trace diagram for the REC wafer plant in Porsgrunn*

duction (pizza production at Orkla Foods and minced meat at Lithells), building material production (Kebony), aerospace and defense production (Nammo), car parts production (Chassix – earlier Alcoa), animal feed production (Felleskjøpet) and many others.

7.5 Some other projects in Prediktor

In addition to the main Prediktor efforts related to MES systems, we were engaged in many development projects for various customers. Some of these are mentioned below.

7.5.1 Oil production separator train control

In the period 2004 – 2007 I was involved at Norsk Hydro in optimal control design for oil production separation trains. Slugging flow estimation for use in control was part of this as well as PID controller tuning and comparing this with model based control (MPC).

7.5.2 Optimal control of oil well production

This was a project initiated and owned by Norsk Hydro where Oddvar Grønning and I participated from Prediktor. The theme was how to schedule the individual wells in an oil-rim reservoir, exemplified by the North Sea Troll field, for optimal production, Mjaavatten et al. (2008).

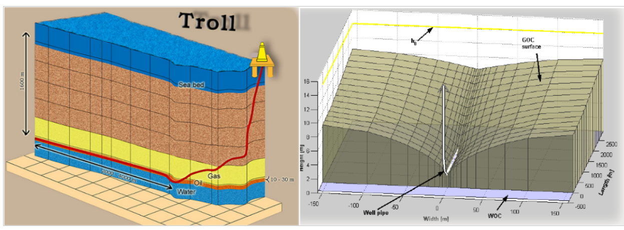

Figure 17: *Troll oil field well model geometry*

In such oil fields a thin oil layer lays between an aquifer and a gas cap. Oil may be produced from such fields by use of horizontal wells. Production will lower the local gas/oil contact (GOC) near the well in a process called gas coning (see Figure 17). After gas breakthrough, the gas/oil ratio (GOR) from the well may vary strongly with the production rate. The ability to predict this dependency is essential for production optimization for such fields. A simplified model for the oil field was formulated and turned out to perform well (see Figure 18).

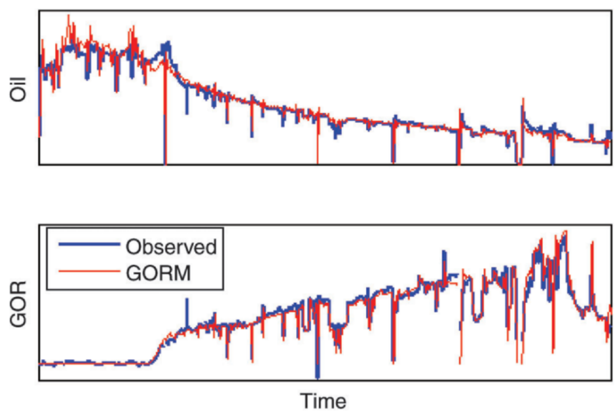

Figure 18: *Real and simulated behavior for a typical Troll well over 2-years. Note how the GOR increases, and the oil rate declines after gas breakthrough at approximately 5 months*

The model forms the basis of the GORM (gas/oil ratio model) computer program that, since early 2003, is in regular use for production planning and optimization at the Troll field.

7.5.3 Ormen Lange

An important project for Prediktor in the first decade after 2000 was the development and delivery of a supervisory system to the Ormen Lange which is a subsea gas production facility connected to an on-shore processing facility via a 120km pipeline. I was engaged in making of an MPC system for controlling the subsea valves according to determined production set points.

The details regarding this are described in Sælid (2019). Espen Krogh headed the project for Prediktor. The project also included infrastructure for flow assurance, for look ahead simulation and estimation based on APIS software as well as flow assurance software from Scandpower (later bought by Schlumberger) and software from FMC. See also Figure 19.

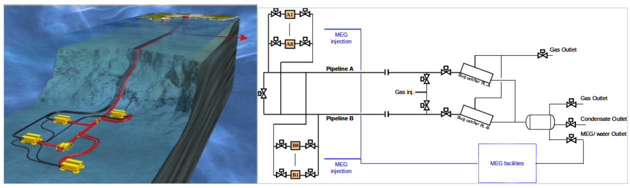

Figure 19: *Artists view of the Ormen Lange transport pipe system (left) and a simplified system layout of the gas/MEG/condensate system*

Figure 20: *Amphibious sea and land vessel (T-Craft) from Umoe*

7.5.4 Work for Umoe

In the years 2007-2008 Oddvar Grønning and I worked on a project for Umoe in Arendal. Umoe had developed a concept for an amphibious sea and land going vessel (T-Craft). This was a project for the US Office of Naval Research, and we made a study of dynamic positioning of such an amphibious vessel for travel on land and sea, as well as a control and simulation system for mother T-Craft launch and return connection.

The system was not ordered by the US due to the changed policy introduced by President Obama, but the project was a really challenging one where we used MPC technology for control. A complete simulator for this system was developed by us.

7.5.5 Work for Kongsberg Maritime

After having switched from holding the CEO position in Prediktor to the CTO position I was engaged by Kongsberg Maritime for two projects. The first one was to make a review and propose potential changes to the new KCS system (Kongsberg Control System) architecture and design. The KCS system should still use the real-time kernel (with improvements over time of course) that was developed in the 1980s as the AIM system. The new part was to introduce an OPC UA based server for reporting, support higher level applications, HMI support and other user data access based on information modelling. Stian Larsen and I from Prediktor, together with internal KM people made the review and proposed a few changes that were made, and I think this resulted in a simpler, easier to configure and understand and to a more robust system.

The other project related to the fact that Kongsberg was planning to start up an activity within the field of wind energy supervision and control. Oddvar Grønning and I made a wind- and windmill simulation model to support the start of this activity. In order to support this we tested out various control methods, such as classic PI control, model based predictive control and max power production seeking algorithms, based on the fact that the power generation from a windmill is a nonlinear function of the pitch blade angle and the rotor tip speed relative to the wind speed as shown in Figure 21. C_p in the figure is proportional to the windmill power production.

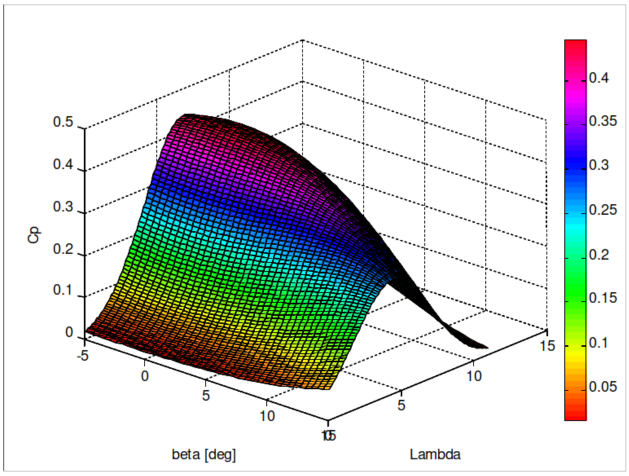

Figure 21: *C_p plot as a function of windmill blade tip speed ratio and the blade pitch angle*

This work turned out to point forward to the present Prediktor involvement for supervision, management and operation of renewable energy plants/systems. This will be described in greater detail later in this paper.

7.6 Industrial and Medical Instrumentation

This activity did not end so well. The starting point was the need that food- and feed producers had for measuring product quality parameters in their products in real time, such as fat contents, and moisture or other parameters in produced feed-pellets or in food products. It was well known that these parameters could be measured by using near infrared reflectance spectroscopy, so we rented a heavy laboratory instrument at the end of the 1990s of this type from Foss in Denmark and tried to use it online.

That was partly a success, because it worked, but also unsuccessful because it was not made for robust and reliable use in harsh industrial environments. So, I thought we could make a robustified industrial version ourselves in Prediktor, which we then did. The result was the cylindrical steel instrument shown in Figure 22, measuring on minced meat by analysing the reflected light spectrum and a multivariate calibration model adapted to the specific type of product.

Figure 22: *The Prediktor Spektron 1700 process NIR instrument*

This worked well and Prediktor sold a few dozens of these during the years to come. The earnings and the business were ok. In June 2012, an unfortunate thing happened to me. I got a brain stroke. Luckily, I survived, and my brain was mostly intact, except for walking balance problems and a slight change of my voice which remains. During the recovery from the stroke, the nurses measured my blood sugar by pricking my fingers for blood samples for blood glucose measurement. They also measured my blood oxygenation optically using red LED lights (LED = Light Emitting Diodes) and a measuring device put on my finger for that. The engineer in me wondered if blood glucose could be measured the same way. I had a PC and an internet connection in the Sunnås hospital, and I soon found out that the idea had occurred to others as well, but no product based on this worked satisfactory. But I thought: Maybe the combination of our experience using process NIR and our ability to use dynamic models and Kalman filtering could be the links for us to develop a wearable non-invasive working device for blood glucose measurement. I talked with my colleagues Terje Karstang and Espen Krogh, and we agreed on applying for development support for the proposed project. The drawing to the left in Figure 23 is taken from the application.

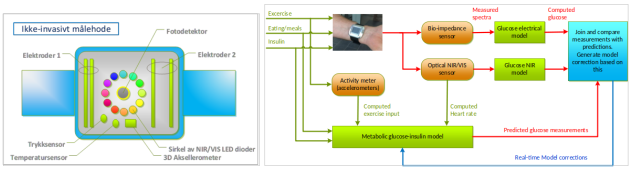

Figure 23: *Concept drawing for the wearable blood glucose device*

Later we got investors into the project and founded a new company, Prediktor Medical. Espen Krogh became the CEO of that company, and we developed the BioMkr device as shown in Figure 24. The gains would be enormous if we succeeded with glucose, but the probability of not making it was significant, but we thought: If you never try, you will never get there. Close to 10 000 patents existed for non-invasive glucose measurements and tens of failed companies existed for doing this. Our early proposal for joining the medical company with the industrial instrumentation part was turned down by the biggest investor in Prediktor medical claiming the focus mantra. I think that was a very bad decision. After 6 years of research the conclusion was that we did not make it (yet). The device worked in some cases (when sitting quiet in a chair), but the noise generated by activity was too large and the spectral sensitivity was not sufficient in the most important wavelength ranges. But we were close.

The challenge in measuring glucose in blood is due to the very small concentrations of glucose in blood and the frequent disturbances due to blood flow variations, temperature and tissue motion in a living person. The normal concentration of glucose in blood is in the range of 100 − 200 mg/dL. This means a concentration of 0.1% of the total blood content by weight. A useful measurement of this should have an accuracy of at least 10% of this, meaning an absolute accuracy of better than 0.01%, whereas an absolute accuracy of

Figure 24: *The prototype (left), exploded view (middle) and hospital testing (right)*

0.1% is fantastic in most industrial settings. In addition, the setting is much more stable and controlled in most industrial cases.

As already said, Espen Krogh and I, and the people in Prediktor Medical all proposed a merger between Prediktor Instruments (the industrial measurement company) and Prediktor Medical already in 2018, based on the risks of the technology and the obvious possibility to make it useful for industrial use. Three years later, when the problems with making a sufficiently accurate blood glucose sensor surfaced, Prediktor Medical was merged with the industrial instrumentation activity in Prediktor. To adapt the results for industrial use, some small new investors came in. The resulting device, D20, was very close to success (we think), but the money ran out and the company had to file for bankruptcy.

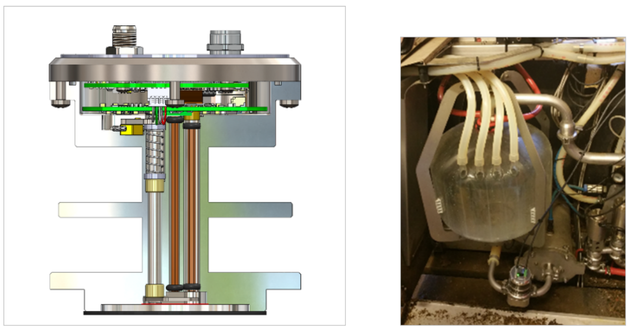

Figure 25: *The D20 drawing (left). Mounted on a milking machine to the right (at the bottom in the photo)*

The main reason for the glucose sensor failing, was the insufficient signal to noise ratio achievable at the proper light wavelengths. I am convinced that the technology will arrive in a not-too-distant future, but we were not blessed to possess that technology in our time.

7.7 The Renewable Energy Transition and New owners

In 2022 Prediktor was acquired by TGS. TGS is originally a geophysical company that is now expanding its activity from subsurface geophysical and seismic data analytics. TGS is now actively expanding into the renewable energy sector. That is where Prediktor fits in with products and experience within this field. I see Prediktor and Prediktor's cybernetics and physical/information modelling abilities as well as related software for real time operation as very well positioned to participate in this. Some focus areas for Prediktor in its new home will be:

- Solar and other renewable energy systems asset management and associated SCADA (Supervisory Control and Data Acquisition) systems.

- Software solutions for combining several types of renewable resources to mitigate the stochastic and intermittent nature of wind and PV power by using energy storage technologies such as batteries, hydrogen or other means.

- Participate in making systems for carbon capture and storage (CCS).

I think that the TGS acquisition is good for Prediktor. Cybernetics, optimization and systems thinking will massively be needed to make the transformation of the energy system from coal- and hydrocarbon based to renewable energy based and I will participate in this as long as I am useful for participating in this.

8 Final remarks

So, what did I do during 50 years in cybernetics? I worked in many corners of the field. Norbert Wiener defined cybernetics as ”...the control and communication in the animal and the machine ...”. I have mostly worked with machines but also touched on the use of cybernetics in living material such as humans and in biosystems in the Havbiomodeller project.

And what did I learn from it, except for the technical details? And what is the status of cybernetics today?

First, to succeed in cybernetics on a practical level, you need an open mind and the ability to learn in a broad context. Cybernetics is extremely cross-discipline. You may of course dive down into details, such as stability proofs or optimization algorithms and make an academic career out of that, but to get things to really work, you need a bit of knowledge from mathematics, statistics, sensor technology, of course basic control engineering, how to approximate complex mechanisms and you need knowledge about the system you work with, such as how the human body works if you are trying to make glucose control systems for diabetic humans.

Secondly, in my opinion, things are not moving as fast as they seem to do. The article McCulloch and Pitts (1943) introduced neural networks. That is almost 80 years from now. In the present hype related to AI (Artificial Intelligence), one should remember that the official birth of AI was in 1956, Moor (2006). AI, neural networks and machine learning are of course boosted by the computer capacity development. So, many of the basic concepts and theories of AI are not new, whereas AI in the fields of natural language analysis and synthesis or other applications based on huge amounts of data, such as advertising, ChatGPT and Google Lens are really new and impressive. My main point, in the context of engineering cybernetics, is not to forget model based control- and estimation based on first principles- and lower dimensional models.

Another temporary hype is the concept of digital twins. Digital twins are models describing some aspects of a real system. But digital twins have been around since the first computer being built in the 1940s. When I started out in cybernetics, digital twins were the central theme: Modelling of processes for understanding and control, but the name is relatively new, coined by the US space organization NASA in 2010. The digital twin term was actually first used in 2002, Grieves and Vickers (2017).

In my opinion, engineering cybernetics and control theory have not changed much during these 50 years I have spent in this field. What has changed is the incredible increase in technically available computing- and communication capacity. The technology landscape generally has also changed. New processes have appeared, and cybernetics are often applied for their realization and working. A few examples of this are: Robots, drones, use in cars, use in advanced electrical batteries technology and many, many other places.

So, cybernetics is a field where the methods and the theories are quite mature, but the application areas will come up paced by the development of new products and production processes and the general development in the technology field.

As I see it, the quite stable and well-developed methods and science of cybernetics and control has a bright future, especially for applying this to new products and processes. One example of such developments from my career was the dynamic positioning of vessels. The methods existed, the vessel technology existed, and the DP development was mainly about applying known methods and technology in new and better ways.

I'm convinced that many more of this type of opportunities will appear all the time in the future. This will require an obvious and important position for engineering cybernetics in engineering education and research. It is a kind of set of methods for making stable operable and well-functioning systems!

Engineering Cybernetics has for me been a tool to understand, control and make things. Cybernetics is a strange mix of deep theory and applicable methods. And the world is filled with systems made by man and other systems such as the human body. Thousands of control loops are active in a human body to make possible a life for many, many years.

My focus has been on applications and to get things to work. I think that is in line with Jens Balchen's work and mind. Today, the Engineering Cybernetics department at NTNU has people working on deep theoretical issues as well as on the applied side. These are mutually supporting activities. The danger is to destroy this balance. The famous John von Neuman stated (somewhat shortened) in his essay The Mathematician from 1947: "... mathematical ideas originate in empirics. But, once they are so conceived, the subject begins a life of its own. It becomes more and more purely aestheticizing. At a great distance from its empirical source, a mathematical subject is in danger of degeneration. In any event, whether this stage is reached, the only remedy seems to me to return to the source: the reinjection of more or less directly empirical ideas."

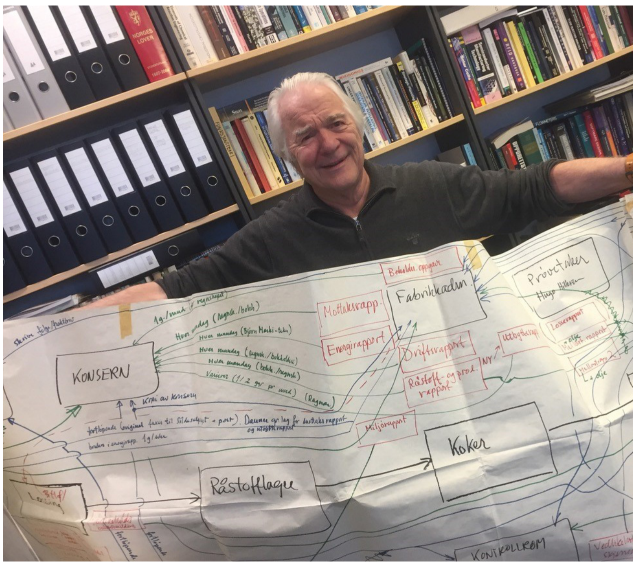

Figure 26: *Steinar Sælid towards the end of his career*

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