Maurice Bonney (1932 -)
Some computing, systems, production control and higher education experiences

Content

This note is a summary of my career and experiences. It shows how my career developed but, more interestingly it describes some of the early computing experiences, some production control experiences and also includes some wider reflections about systems analysis and design. Inevitably the account is personal but I hope that it adds another piece to the jigsaw that is the totality of early computing experiences.

Brief Career Summary

1953 -1955 National Service Education Officer, Royal Air Force Education Branch
1955 -1961 de Havilland Propellers: Dynamics Engineer, Systems designer, Head of OR
1961 -1965 Renold Chains: Individual 4 (Senior Programmer)
1965 -1983 University of Nottingham: Lecturer, Senior Lecturer, Reader
1983 -1986 Loughborough University of Technology: Prof. of Manufacturing Organisation
1986 -1996 University of Nottingham: Professor of Production Management
1996 -date Post retirement activities: Emeritus Prof. Operations Management Group, Nottingham University Business School (NUBS)

The approach

The content of the note broadly follows the sequence of the Career Summary above. Although they are obviously highly inter-related, I was always more interested in potential applications and their successful implementation than in computer developments as such. Although ‘systems’ ideas have developed greatly since my early experiences, there are many system design problems that are in need of solutions. Some of these are discussed. People remain the main limitation to systems implementation.

My early work experience

I started my professional career in 1955, when I was 23. I was lucky that the work soon involved computer projects and the technical and social complexity that went with them. 1955 was early in the development of computing. The computer systems that were available at that time in some ways matched my experience of life; somewhat limited. I had been brought up in a two child family that, because of the Second World War, was moved to an area that was not greatly affected by the hostilities. I attended 2 primary schools in Southport, 2 grammar schools, one in Southport and one in Sutton. From there I went to Manchester University where I read mathematics. While at university, I took vacation jobs to earn some money and to obtain some technical experience. One vacation job was with the Directorate for Colonial Survey that was mapping the colonial empire still administered by the UK. Surveyors’ traverse data, photogrammetric aerial survey data and least square methods were used to map the terrain. Inevitably the work involved many tedious operations on hand and electric calculating machines. This probably primed me to be receptive when later I had the opportunity to use computers for scientific calculations. Mapping was an interesting application of complex variable analysis.

After graduation I became a National Service Education Officer in the Royal Air Force. This provided excellent organisational (in charge of 120 airmen, i/c station tennis, team manger of rugby football, deputy i/c technical library) and teaching experience. My social interests were in sport and outdoor activities and the usual enthusiasms of a single unattached male!

When I was demobilised in 1955 there was, as now, a shortage of mathematicians and there were many job vacancies. I was interested in applying my mathematical and scientific background to practical problem solving and so I sought employment in the major developing science based industries. The industries that matched my perceived needs at that time were the electronics, aerospace and nuclear industries. After a small number of interviews and visits, I accepted a post in the aerospace industry because it seemed exciting, it faced many technical problems at the forefront of knowledge and it appeared that it would provide an excellent training environment. Separately, my Royal Air Force experience had made me interested in flight and electronics as well as efficiency and management. Broadly, that was how in October 1955 I started work as a Dynamics Engineer in the design department of de Havilland Propellers, the prime contractor for the development of an air to air missile that later became known as Firestreak.

In addition to performing missile design calculations and analyses there was a need to learn about missiles, control systems, several unfamiliar areas of mathematics and to become familiar with the company culture. The calculations included analysis of telemetered flight data, and mathematical analysis and calculations of linear control models that represented the missile and its flight. Mathematical and computer modelling were central to the work. The models related to the whole product and also to individual missile modules and subsystems e.g. the aerodynamics, the guidance system and the control circuitry. Mathematical analysis mainly used Laplace transform methods. Models of the missile system ranged from completely mathematical models to models that were part hardware and part analogue computer model. The analogue computer models could be linked with parts of real subsystems e.g. the guidance system. Model variables included possible target manoeuvres; engine thrust profiles and more subtle design variables e.g. the effect of different filters, usually chosen to reduce unwanted oscillations in the control system frequency response. After about a year, I transferred within the same department to the digital computer section to join a team that was developing digital computer flight simulations. Some of the work used relatively simple models, typically representing a missile by 8 simultaneous, mainly linear, differential equations. There was also a major new project in which I became actively involved that was developing a 3d flight simulation model. Eventually this model used more than 100 non linear simultaneous differential equations to represent the missile system. This digital computer model included representations of the control system, the guidance system and the aerodynamics. Further learning was required related to numerical integration methods, mainly Runge-Kutta, and to program the Ferranti Pegasus computer. I attended courses on numerical methods (given by Sandy Douglas) and on 'management' at what eventually became Hatfield University.

An early experience of using a digital computer occurred one evening in 1956 when we used the LEO 1 computer at the J Lyons' headquarters at Cadby Hall, appropriately roped off because our work was 'secret'. Later, more detailed work was done using a Ferranti Pegasus computer, initially at the Ferranti computer bureau in London but occasionally using another Pegasus at Armstrong Whitworth in Coventry. Some time later, de Havilland Aircraft Ltd, which was located on the other side of the de Havilland airfield at Hatfield, purchased its own Pegasus computer. Peter Barnes, a fellow graduate from Manchester was their computer manager. De Havilland Propellers became regular users of this machine and in 1957, I became leader of the computer section.

Interesting problems that arose included:

- Using the LEO 1 interactively to perform flight simulations. This was achieved by having a pack of pre-prepared punched cards that were selected by the operator/programmer to represent the initial conditions for the next run of the simulation. The selection was based on the results just obtained which we plotted on graph paper and then interpreted. The primary aim was to obtain a better awareness of the flight response to different initial conditions and to achieve this as efficiently as possible.
- Using Pegasus to produce safely zones, i.e. to identify places to avoid should a missile malfunction occur under different flight conditions. Technically, the problem has similarities to generating human reach profiles and to robot safety problems each mentioned later.
- Using the 3d flight simulation to perform calculations that were at the limit (requiring roughly 6 hours run time to simulate a 10 second missile flight) of the computing power of the Pegasus which, if my memory serves me, had a mean free time between errors of about 1 hour. To enable work to proceed, intermediate results were saved at convenient stages of the calculations roughly every hour or less. *(FL: LEO standards set approximately 20 minutes as the time before restart data was saved)*
- The same 3d simulator was used to examine re-entry problems for Blue Streak, the UK inter-continental missile venture. The reason for the investigation was to see whether there were conditions under which a missile on re-entry from space could bounce on the atmosphere. Unfortunately, an intermittent computer fault meant that the missile appeared to (incorrectly) do just that. It bounced! However, other puzzling indications meant that, after major computer maintenance, the work was repeated and the missile simulation showed that bouncing would not occur under the conditions evaluated.
- Using optimum programming of the drum of the Pegasus so as to speed up the calculation time.
- Writing our own sub-routines for sines, cosines, etc. based on Chebychev polynomials primarily to fit in with our optimum programming needs.
- Using a combination of mathematics, hand computing, digital computer simulation, analogue computer simulation, testing hardware in the laboratory using analogue computer models to replace some components, and using flight telemetry data to cross check simulations with reality.

Using mathematical analysis, digital and analogue computer modelling and practical work – laboratory and flight data – in combination is clearly important for product design and systems investigation. I think that cross checking using more than one method is even more important for management, economic, environmental and political decisions than it is for product design and that, although hunch is important, it needs backing up with pilot schemes, experiments and detailed analysis. Surprisingly, even today, simulation, let alone experimental work, is not always used, even when it has obvious potential benefits.

Overall, and probably as important as the above, it was clear that, as designers, we were dealing with at least two highly complex systems; the missile system and the computer system. In general, because missiles were a new technology, incremental solutions were not appropriate. However, it was also clear that other systems were involved. First, the missile system needed to respond to changing external threats and opportunities e.g. the changing capabilities of the 'attackers', and defensively, changes to the fighter aircraft that would carry the missiles and, within the missile, the developing technology of system components could provide other possibilities. Also, the missile system was embedded in a broader complex man machine system that included the management of the projects, the cost of the projects and the domestic and international politics that coloured the government's attitudes to the defence industry and the projects that it would support.

The complexity alerted me to a need to learn more about other disciplines such as systems analysis, operational research and cybernetics, and also about the detailed techniques that were used within these disciplines. The incentive increased when, armed only with a superficial knowledge of these fields, I was asked by the company to write a feasibility report about the possibility of using computers within the company to help plan and control the production of its products. This, and the challenges that complex systems presented, encouraged me in due course to apply for an internal transfer to the new Organisation and Methods Department that was being set up to improve the production performance at the company's main production facility at Lostock near Bolton; which, at that time was believed to be the largest job shop in the UK.

I was accepted for the job and transferred to the Lostock factory in March 1959. The remit was to examine and implement an integrated data processing system particularly focussed on production control but which would accommodate also the company's administrative systems including finance and personnel. This was a new and exciting challenge. Organisationally, the company had recognised the importance of the work and appointed an experienced Production Organisation Director (John Grant), who was responsible for strategy and who reported directly to the Managing Director of the whole company (Sturgeon). They also appointed a highly experienced O&M manager (Harry Washbrook) to be operationally in charge of the new unit and they transferred an experienced control systems engineer, Stan Demczynski, from Hatfield to head up the technical systems work. Many other bright and enthusiastic persons were employed. It was a strong team that was supplemented as required by technical and commercial apprentices. The team was organised into 3 groups corresponding to short, intermediate and long term activities.

The short term group performed conventional O&M activities that paid for themselves as they progressed. Much of the work was straightforward; e.g. improving the internal postal system. Also many superfluous activities were removed e.g. by eliminating copies of reports that were not relevant to the managers concerned, merging some reports, etc. This meant that the administrative systems at the factory became progressively more structured and many trivial anomalies were removed. As a consequence the company's systems improved and its system strengths and weaknesses became clearer.

The company already had a small Power Samas programmable (120 program steps) punched card system that had been purchased to perform accounting operations but was not being fully used. The intermediate team was instructed to use the equipment to gain experience by producing a punched card based production scheduling system. Among other things this would obtain and use some of the data that would be needed whatever production control system was going to be implemented in the longer term. The intermediate scheme required a lot of data processing and so another Power Samas computer was obtained. With urgency the 2 computers and associated punched card systems were used to move from the 'heap and hope' approach then used and then to implement a simple system for scheduling machining operations called 'backward scheduling to infinite capacity'. Roughly this subtracted the standard operation lead time from the required by time in order to derive an operation start time. Backward scheduling is described in Appendix 3. The new system greatly improved the factory planning. More items were produced on time and the value of work in progress was reduced by millions of pounds valued in 1960 pounds. The improvements were rapid but soon levelled off; the performance got stuck. In other words a great deal had been achieved but much remained to be done and we could not see how the intermediate scheme would achieve that! The resulting control system was claimed to be the second operational computerised production control system in the UK. The first was commonly believed to be the ICT system at Stevenage. Some data related to the intermediate scheme appears in Appendix 3. (to collect)

While the short term and intermediate groups were making visible progress, the long term team, headed by Stan Demczynski and of which I was a member, were examining the feasibility of producing a fully integrated production control system. To convert ideas into practice, the operational systems for the whole factory and their interfaces with the designs and orders originating from Hatfield were charted in detail and then summarised. From these summarised charts and our interpretation of the company requirements, we produced system charts for the proposed new system along with assessments of the volume of file processing and evaluation that was required, outline file contents and options for scheduling. Analysis of data from the intermediate scheme helped to define the file requirements and indicated the scale of the scheduling problem that would be faced.

An exciting trip for me during this period, probably early in 1960, was to visit the IBM Sindelfingen plant in Germany. It was stimulating to see a modern plant and a computerised production control system in operation but particularly to feel almost tangibly the management's enthusiasm for Jay Forrester's Industrial Dynamics ideas that offered the possibility of using control systems analysis and simulation to investigate the performance of management and other systems. My personal experience, the team's experience and the company's experience of missile design and control systems analysis made this a very appealing possibility. Shortly afterward, possibly related, I was sent on Operational Research courses, and then given the grandiose title of Chief of OR. The main practical effect of the visit and courses was that, as part of our systems planning, we tried to ensure that appropriate data would be available for eventual use by algorithms that would help operational decision making. Many possibilities relating to different scheduling approaches, management and financial information systems were considered and reports were produced that summarised the proposed new production procedures and the proposed new administrative system procedures. In LEO's terminology these were more detailed than a feasibility report and were something close to a job plan. These proposals were to be used as the basis for purchasing a powerful computer to implement a new PPC system. Three recently announced computers; the IBM 360, the LEO III and the English Electric KDF 9 were shortlisted. Eventually a KDF 9 was purchased for compatibility and one was being purchased at Hatfield for its scientific computing possibilities. However, when the decision was made it appeared that the technical computing requirements of Lostock were virtually ignored in the decision making process e.g. the KDF9's file handling capabilities at that time waere fairly primitive.

Unfortunately major management problems developed within the Lostock O&M group (I suspect as a result of a Tony Blair and Gordon Brown type situation between Grant and Washbrook) that ended up with Washbrook leaving the company. This triggered a major a major change in the group dynamics of the team and sadly the team broke up. That really was a great waste. Although we had been relatively low paid, progress had been good on all fronts, we had all gained fantastic experience, the company had made major improvements and the team felt that it was poised to make even greater improvements. Virtually everyone who decided to move for whatever reason found employment very rapidly at enhanced pay, although I suspect not generally employed on such technically interesting work. The outcome was that within a short space of time, two of the staff set up consultancy companies, others joined different companies, one became a university lecturer, etc. Washbrook progressed elsewhere and his name remained prominent in the Institute of Management Services for many years.

Also around that time, as a result of government pressure the company was changing on a wider scale. Over a short period of time we were renamed de Havilland Aircraft, Hawker Siddeley Dynamics in 1960, and then British Aerospace Dynamics. This was part of the rationalisation of the aerospace industry but uncertainty from this type of change makes it difficult to decide what the new production control requirements should be particularly as the computer industry was also changing rapidly.

Years later when I was at Nottingham University I returned to the Lostock factory to visit a student (now a professor) who was on a 1-3-1 apprenticeship scheme at the factory. The KDF9 had been replaced by an IBM machine. However, although there was much more computing power, it appeared that the production control system had changed little from the backward scheduling to infinite capacity production control system outlined above. Integration was still a long way off.

Renold Chains Ltd.

In May 1961 I took a position as Senior Programmer at Renold Chains Ltd in Manchester to work on a very different kind of integrated data processing. The work consisted of attempting to reproduce the company's manually operated production procedures. This so called ‘pilot scheme’ was to be developed by a small team of systems analysts and programmers in Manchester working with a larger team of LEO Computer programmers that were using the LEO III computer bureau located in Whiteley’s Store in Bayswater, London.

Renold was started by Hans Renold (1852-1943) who came to England from Switzerland in 1873 and bought a small textile chain making business in Salford in 1879 that became the Hans Renold Co. The company has a respected history and the progress of the company is well documented. Hans Renold invented the first bush roller chain in 1880. Through the efforts of Hans Renold and his son, Sir Charles Garonne Renold, the company made major contributions to engineering inventions related to chain design and their manufacturing machinery and processes. They also introduced the Scientific Management movement to the UK. Interesting innovations included introducing a Works canteen in 1895, the 48 hour week in 1896, the Hans Renold Social Union in 1910, a profit sharing scheme in 1922, etc. In 1913, Hans Renold presented a paper on Engineering Workshop Organisation, in which he described the functional organisation charts that the company used and the monthly company accounts that were produced. Other innovations included originating budgetary control, joint consultation, a bonus scheme, and the use of system charts. Sir Charles Renold became the first chairman of the BIM, formed in 1947.

The company became Renold Chains Ltd in 1954. It had taken over many other companies and was a major manufacturer of many kinds of chain from bicycle chains, car timing chains, chains for diesel power transmission, conveyor chains for the mining industry and specialist chains for a wide variety of applications. The production procedures were a complex set of sophisticated manual procedures that planned production based on a variant of a base stock system (explained in Appendix 2) that had been developed by the company in the 1930’s. Essentially the company set a target for the number of weeks of stock that should be in the pipeline for each stage of manufacture. Using these targets in conjunction with known current stocks, the procedures determined the quantities of material to order and the number of parts to make and to assemble. Detailed control was mainly of the first and the last operations and the planning staff had discretion to distribute the intermediate work over the machines to make the best use of current conditions. Material, work in progress and finished product stock records were updated manually from material receipts documents, work move notes and product despatches. Cost and bonus calculations were also produced.

As far as possible the proposed computer system, the ‘pilot scheme’ was to replicate the manual procedures, but additionally the company wished to produce cost centre statistics and a range of performance reports. The method used in the new computer system to derive the 4 weekly guide production quantities was a novel heuristic method which actually calculated production numbers and schedules for the operations to be performed on each chain component for each week. These schedules were then converted into 4 weekly composite figures in line with the 4 weekly planning cycles being used by the manual schedulers. The idea was broadly to mimic the general characteristics of the manual schedulers but we felt that it was necessary for the computer to calculate feasible weekly production numbers in order to avoid occasionally setting the manual schedulers impossible targets. Privately, we felt also that having the weekly figures available could be a stepping stone to moving in due course towards a fully computerised scheduling system if that was later felt to be desirable. The production procedures used approximately a hundred input documents and produced a hundred different types of output document. Of course all of these had to be redesigned so as to be suitable for data input, systems had to be redesigned so that the data went for processing at the correct time and output documents redesigned so as to be suitable for computer output. At the time, the Renold project was probably one of the biggest bureau based integrated system in the UK and the whole project was one of the largest integrated production systems under consideration.

Renold had a very stable workforce and used a policy of rotating staff in their management posts, and so, unusually for a company, virtually all the staff knew the Renold operational procedures. If one went to discuss the operation of their system with the line manager, he would bring out a procedural chart that I suspect had been produced in the 1930's but still accurately reflected the company's operational procedures. Hence, systems analysis was very different in Renold from the analyses that we had undertaken at de Havilland and at most companies that had grown like Topsy and which required a detailed investigation of the systems that they were using before systems staff could understand sufficient to develop a new system. These comments might suggest that Renold would be an ideal environment to produce disciplined computer systems. Unfortunately, several things invalidated that assumption. Most of these only became clear as our investigations progressed and the computer system was developed and tested. However, a good feature of the systems checking was that we produced systems charts that not only showed the document and information flow but also showed the calculations that were to be performed with real numbers entered. This made understanding much easier and it allowed computer calculations to be checked <u>before</u> they were produced. This made understanding much easier. Discussions between staff and analysts used the same language and the results from the computer were clearly 'right' or 'wrong'. Figure 1 of Appendix 2 shows a typical Renold systems chart.

Despite the excellent systems investigation, it became progressively clear that something was fundamentally wrong e.g. staff of departments that we were dealing with were seemingly more pleased when we had difficulties than when we had success. The awareness dawned only very gradually. Almost jokingly, a long time before reality struck, we described the situation by the necessarily censored acronym; BBFUSM. The more successful we were in computer terms, the more closely did BBFUSM describe the situation on the ground. (*Biggest bloody f*** up since Mons*). Some particular situations that remain in my memory are:

- After major faults had developed in the manual system because of an influenza epidemic, the computer files were used to reconstruct the manual files that were being used by the company. This was the natural thing to do but did not lead to the obvious next step – the company thinking that there could be some merit in using a computerised approach.
- A typical time for the manual system to produce the company's year end statistics was 3 months whereas the computer produced them the day after the year end. Any differences in the content, which was the basis on which we were to be judged, were traced to errors in

the manual system but again apparently no brownie points were awarded to the computer system under test or to the computer staff!

- Eventually, the company agreed that the new computer system was a technical success and worked in its entirety. The scheme had involved approximately 50 man years of work spread over nearly 3 years and, when decision time arose, a meeting of the relevant company committee agreed that the scheme had been a success and that the company should buy a computer. The next question was what should the company do with it? The decision was made not to use the extensive 'pilot scheme' but to work on the sales procedures. In other words, however well we had done, the end result would have been the same; the work would have been ignored!
- The senior systems analyst was promoted to become Employment Manager

LEO provided excellent help with the programming and file handling procedures. They also provided intermittent systems analysis guidance in the form of an analyst who was well respected by our systems staff. However, it was not clear to us at the operational systems level what contacts LEO were having with the senior Renold management or whether they were trying to influence the company political issues.

Observations (with contributions in red from FL who knew the Renold management)

- The management style of the company at that time was strange, certainly not dynamic. It was traditional, hierarchical and any suggestion for change was difficult to discuss because it was 'not Renold'! Despite an obvious benevolent attitude in general terms, people were not brought in to contribute ideas but to do what had been decided. Graduate apprentices did not stay! *(FL: A nice example of the role of tradition in the company is that at lunch the managing director carved the roast!)*
- The manager nominally in charge of the systems design group did not participate in any decisions. Over the duration of the project (3 years), his sum total of involvement was no meetings, no decisions and virtually no memos or telephone calls. Apparently, all decisions were taken by the Finance Director.
- There was a dispute between the Production Director and the Finance Director, *(FL: It was the Finance Director who had been the computer champion, and it was he rather than the Production Director who had chosen the production procedures scheme as the pilot application).* In reality this meant that the objective of the 'pilot scheme' was not to develop a system to be used but a system that could show that it could be used. The computer was a tool in a power struggle. Although this was not known by us at the time, apparently the Production Director did not believe that the scheme could be made to work. If this surmise was correct, it probably explained why the better the pilot production procedures worked, the more resistance there was from the production personnel.
- The company systems were structurally excellent and were operated by intelligent well trained staff. Despite this, in the past the company had seemingly made some very strange operational decisions. For example, the company typically allowed 6 weeks to produce a chain. Not only could a chain be made in a much shorter time but more importantly, when one examined the data, the stock turn was roughly once per year! The base stock system (see Appendix 3), is a production/inventory planning system that can be a very effective tool to control and often reduce stocks. As far as I could gather the system was designed by Renold in the 1930's whereas the first description of it that I have come across in the

academic field is in McGee (   ). Apparently, the high level of stocks was chosen because Renold had on one occasion in the past run out of stock. The company supplied the motor industry with timing chains and was required contractually to supply these within a short time. They therefore applied a 'belt and braces' policy but to such an extreme degree that, there was enough stock available to maintain a full schedule of deliveries even if material was not received, parts were not made and products not assembled. The high planned stock levels were compounded by the GWM factor (the general works manager's flexibility factor that was applied on top of the already generous planned stock levels) and the AS factor (the American standard factor), another flexibility factor that had originally been applied if there was spare capacity in the company at the time that Renold were stocking a warehouse with chains for the US market.

Comments

- We faced some technical problems when trying to derive the cost centre statistics and the bonus system information. Specifically these problems related to getting acceptance of a standard operation coding system. There were also some difficulties with the management information and reporting systems that were part computer produced and part manually produced.
- Strict discipline was needed to ensure that data was submitted at the correct time. On one occasion during testing, the whole of the previous week's data was resubmitted in error. The data was obviously in the correct format but the consequence was that the system tried to move (on the computer files) components from one location (where they were not) to another (to which they had been moved already). The result was that error reports, both detailed and generic, were generated in great profusion. The unplanned error proved to be a stringent test of our error reporting system.
- Compared with the technical complexity of missile calculations and the combinatorial problems of job shop scheduling at de Havilland, the calculations required at Renold were trivial. On the other hand, the logical complexity and the involvement of many staff that lay behind a well planned and documented integrated system was almost unbelievable.
- Although both de Havilland and Renold were traditional and hierarchical even compared with the Royal Air Force, it was also clear that, de Havilland although working on defence projects, was much more open than Renold. Renold, despite its commitment to 'scientific management' was very hierarchical and expected the work force to do what management had decided should be done. An interesting description of some aspects of this appears in (ref) that discusses the operation of the bonus scheme. Quotation required.
- As will have been gathered from the above description, the work was frequently frustrating. Nevertheless, the overall personal experience was highly interesting and complemented the de Havilland experience well. However, Renold's decision to throw away 50 man years of work that had produced a well documented, workable system was not an endearing feature and did not encourage me to continue with the company. It also made me wary of committing myself to other companies without finding out more about them.

The Transition from Industry to Academia

When considering my next employment, my probing of the management of several companies that I thought might be an interesting career move, meant that on several occasions I withdrew my application before the serious business of negotiating a contract arose. The problem was resolved when I was offered a lectureship at the University of Nottingham to teach on a new degree course in Production Engineering, the first such undergraduate university course in the UK. Among the things that persuaded me to continue with my application were:

- The boyish enthusiasm of the first Head of Department, Prof Wilfred Heginbotham
- My feeling that even if the working environment did not turn out to be ideal, the experience would ensure that I would become technically more up to date.
- The members of the interview board including the Vice Chancellor, Dean of Engineering, Professor of Mechanical Engineering and others were very positive. If there were political problems they were not apparent at this level as they had been at Renold.

My teaching involvement at Nottingham was to be in systems design, production and inventory control, OR, computer systems and management services. At that time there were few people in the country with theoretical knowledge and practical experience that covered most of these areas. There were also few courses available to learn about the topics. Thus, I came to an academic environment with highly relevant and recent industrial experience but unused to organising and teaching degree level courses and completely naïve about academic research, university organisation and university politics. At that time the University was expanding and encouraging people from industry to join engineering departments. (This was not the situation later, probably because the RAE (Research Assessment Exercises) would not consider company specific reports such as secret reports on missile design or job specifications for computer. systems in the same favourable light as a refereed journal paper. Thus my timing was fortunate to have the opportunity to join the academic community. I was lucky also to have had teaching experience as part of my Royal Air Force National Service. Later, I continued to feel fortunate to have moved to an encouraging work environment that was technical, interesting and human, where I immediately felt at home, where it was possible to walk round the lake at lunchtime, to play tennis and badminton regularly and to purchase good housing in a quiet rural location only 10 minutes from the University.

The University of Nottingham

Thus it was that in 1965 I became the fourth academic member of staff in the Dept of Production Engineering at Nottingham University. At that time, computing resources at the university were very restricted and consisted of a recently installed land line connectio to the Atlas computer at Manchester University. Later, a KDF 9 was delivered and, consistent with developments at most UK universities, extra facilities were added steadily and, despite resisting calls to set up a Computer Science Department, Nottingham remained in the leading pack of universities with respect to the provision of computer facilities.

By 1967 I had established the basis of my teaching and had been involved in project supervision that had included a student project on industrial dynamics that was a good learning experience for both of us. Incredibly the student, now retired, and I are still in contact! Inevitably my Head of Department suggested that I should start some research. As a lone person with no track record and no team to join, trying to start research in the very broad field of production management, there were many possibilities. My Renold experience suggested that I should start a diverse range of studies in case there were unknown roadblocks that would surface later. In reality however, the converse was true: instead of facing obstacles, the general response was encouragement despite the shortage of resources. I therefore withdrew from some areas of research as soon as it was practicable. The remaining areas progressed rapidly.

Interactive Computer Graphics

Some of the research undertaken from 1967 to 1984 interest a wider computing audience. The work related to investigations that produced software with acronyms such as SAMMIE, AUTOMAT, COMPUTE, NULISP, CAPABLE, and GRASP; in their different ways all concerned with the design and evaluation of work places and work tasks. Another common feature of the work was that many of the studies attempted to develop and use interactive computer graphic methods together with heuristic methods to produce satisfactory rather than optimal solutions. Among the analyses were methods and time analyses for manual work and for machining operations, developing methods for assembly line balancing, positioning controls on control panels and developing methods for robot simulation and offline programming. Some of the software became sufficiently robust to be used commercially by industry or by our team undertaking contractual design studies. To ensure that the activities that were undertaken remained relevant all projects were evaluated using industrial applications.

Probably as a consequence of using computer graphics which at that time was relatively rare and visually appealing, we had the unusual academic experience of obtaining a lot of publicity e.g. by being featured on Tomorrows World, in a COI information film, as a Burke Special production, in a FT feature article, appearing on the BBC News to illustrate CAD and later being invited to present the work to a Royal Society Soiree. In particular, the SAMMIE man modelling project and the AUTOMAT work study project appealed to the media who described the work very positively. The consequence was that it became relatively easy to find companies with which to collaborate on the research and on practical evaluation work. It also meant that we became guides and demonstrators for a constant stream of visitors wanting to see the graphics systems for themselves.

By 1974, 5 of my students had been awarded PhD's and I had a constantly renewing team of highly creative research engineers working with me that included some post doctorate research assistants who had helped to develop the basic ideas of SAMMIE and AUTOMAT. The work was broadly in the field of work place and work task design but the projects could also be considered as:

- Attempts to produce generic software to help develop integrated manufacturing systems,
- Examples of the relationship between the cost and value of information
- Ways to evaluate various systems ideas.

To link with later comments, I note that the team usually consisting of between 5 and 10 researchers, existed over about 15 years from 1968 until 1983 when I was appointed to the Chair in Manufacturing Organisation at Loughborough University of Technology, a post that I held until returning to Nottingham in 1986 as Professor of Production Management.

Appendix 1 describes SAMMIE, AUTOMAT and GRASP in greater detail. These projects showed that interactive working was very useful for system development and for explaining ideas to potential users. But before we could get that far we needed to solve many problems in the field of computer graphics for which commercially available software was not yet available. For example drivers for some peripherals were not always available. However, this changed as time progressed and by the end of the period, industrial organisations were beginning to design some aspects of their products using CAD in a variety of formats. Our attempts to link with these CAD systems illustrated the need for and the difficulties of creating integrated systems.

Despite the difficulties, it was clear that there was a market for the products. However, examining possible ways to market and use the products raised many problems about intellectual property, about public funding and exploitation, about getting access to venture capital to form start up companies and about the willingness of established companies to take over prototype products and to handle the transition sympathetically. Aspects of the commercial links and of the systems analysis issues that this raised are discussed later.

Production and inventory control studies

This section describes my university based industrial and academic studies of production control and systems from 1967 - 1984. The work links with my previous industrial experience and with the discussion about the future of systems and computing.

The time taken to manage the projects described in Appendix 1 and the associated group of talented researchers was technically and socially very satisfying but it left frustratingly little time available to investigate other problems to the depth that I would have liked. However, during this time my interest in production and inventory control had not diminished and I pursued ideas through undergraduate project supervision, PhD research supervision and by undertaking work with companies. For example, from 1970 I became involved with Raleigh Industries, the Nottingham based cycle company, on a part time basis initially as Head of their OR group but later, after they had appointed a new internal head, this evolved into a consulting role with their corporate planning department in which OR was organisationally located. This association continued until the mid 1980's.

Raleigh Industries (part of Tube Investments) was an interesting and generally benevolent company that was plagued by some fascinating difficulties. It had good staff with bright and generally well intentioned personnel. The company had a reputation for high quality products. Although the main production unit was making millions of bicycles per year, it treated the manufacture as small batch production and used a functional organisation to produce cycles typically in batch sizes of 25! Product variety was immense and taking account of colour, frame and wheel size and add on extras literally ran into millions of unique specifications. Factory layout was such that a bicycle would travel about 5 miles (8km) to be produced. Advocates of Japanese lean production methods would have been horrified. The company employed many thousands of workers and it was basically a merger of the many UK companies that previously made up the UK cycle industry. In the 1970s Raleigh was operating in an apparently declining market because people in the UK were progressively joining the car owning democracy. Understandably, the company believed its major problem was how to decline profitably. Hence, although there were many changes occurring e.g. examining and reducing product variety by systematic simplification of the bills of materials, improving processes, etc., there was little major investment. Given this lack of investment, a major problem was to prioritise the many activities that needed attention.

After an examination of their production control system, we defined a Raleigh production order as ‘an authorisation to add to the arrears list’ i.e. an order was treated to some extent as at de Havilland in the ‘heap and hope’ sense. Commercially, the arrears list needed much better control. The arrears list was much too long and under these conditions it was the stores that decided what to make. When sufficient components were available to meet the needs of an order then the paperwork that was already there waiting was issued with the parts and the batch was made. In practice, the stores controlled the destiny of the company. Raleigh needed to improve its production control system performance urgently.

By the 1980’s even though there had been steady ad hoc improvements, performance still needed to improve urgently. However, how or why a decision to install a new MRP system was made, I do not know. What I do know is that a well known and well respected consulting company installed an MRP system and, in the week that the system went live, the consulting company publicised the work in its national newsletter. In the same week a senior director of Raleigh went on the radio to announce that the company was unable to produce any cycles because of the installation of a new computer system. Apparently the instructions that had been given about the operation of the system were to do what the computer printed. Unfortunately, it seemed that the printed instructions did not take account of the arrears list problem which was expected to disappear by magic. My only contribution to a meeting of system implementers, a few weeks before the system went live, was to indicate that the decision was highly risky! But the die was cast and what I thought was my relevant experience and influence did not count. Later, when writing this account, a Google search found many references about the company, its products, its good times and difficulties. A 20 page history ‘Raleigh in the last quarter of the 20th Century’ by Tony Hadland was particularly interesting but contained no reference to any systems development.

Completely separately in the mid to late 1970s, I worked on a project linking CAD to the requirements specification of a GEC aerospace company’s production planning and control system. The company’s file management system could not cope with the speed with which design modifications were occurring and so ‘Configuration control’ was a major problem. Many design modifications were known about but were not yet on the production files. What should be made; obsolescent parts to be replaced later, nothing or wait?

Academic production and inventory control studies that were undertaken during this period included:

- Discrete control theory representations of production and inventory planning and control systems developed primarily by Keith Popplewell, at that time a senior operational researcher at Raleigh, who subsequently registered with me as a part time PhD student. The work produced some excellent simulation results based on the use of z-transform methods to examine the stability of systems that combined various production control, inventory control nd forecasting options.(e.g. see refs) The work was well received by the research community. Keith and I met again some years later, at Loughborough University of Technology where he helped me supervise a researcher who was using the discrete control theory ideas to examine the effect of misinformation on system performance (see Refs). For example, if a system erroneously has a stock level recorded as 100 items instead of the true figure of 80, perhaps because of a mistake or because of a recording delay, then when the stock is next ordered, 20 too few items will be ordered. Potentially, this could lead to a production shortage and the system not working as planned. Further work is required to investigate the value of accurate and timely information and the conditions under which misinformation can create system errors, instabilities and costs. Many planning and control systems face such problems and z-transforms are a useful investigatory tool. After some years as an academic at Loughborough, Keith was appointed to a Chair at Coventry University.

- A set of undergraduate projects that investigated investment appraisal of production control systems. Investment in production control provides many advantages such as reduced WIP, more effective use of resources, better delivery performance, etc. but implementing such systems costs time and money. Assessment of the potential gain, which is dependent on the WIP and products stock holding costs and the profitability of the products, can guide how much it would be worth investing in an improved PPC system.
- I was a member of the British Standards Committee that produced BS 5192, a revision of the then rather elderly standard that existed
- I was a member and later chairman of the INTERNET production scheduling working party, whose activities included a survey, discussed later, that examined the relative performance of packages and bespoke software developed within a company.
- Examining 'the factors that lead to success in PPC'. This was a SRC supported project with Dr Schofield as the main researcher. (briefly summarise and references)
- A PhD study performed by Peter O'Grady that developed modern control theory models. Among the results was a generalisation of the HMMS Linear Decision Rule studies; good fundamental work that needs to be further developed to improve our understanding of PPC. (refs) After appointment to a lectureship at The University of Nottingham, Peter moved to the USA and has since followed a highly successful academic career.
- Being involved with several teaching company schemes including one related to planning pharmaceutical manufacture and one related to flexible manufacturing.
- I set up a local (East Midlands) group of the British Production and Inventory Control Society (BPICS). BPICS later became the Institute of Operations Management.
- In 1980 I was elected to the Executive Committee of the newly formed International Society for Inventory Research (ISIR), in charge of the Inventory Management Section. I later became Vice President and then President of ISIR.
- Through ISIR and other contacts, I developed a close interchange of ideas with Prof Robert Grubbstrom, a major developer of solutions to problems in MRP using transform methods and an input output representation of MRP. The contact remains active.
- In 1986, I was invited on an extended visit to China, primarily to discuss CAD. Interestingly, on a visit to the Xian Aircraft Factory, my schedule was changed and I found myself presenting a seminar on production control. Their production control system was

virtually the same as that at de Havilland in 1960. The exchange of experiences was interesting and possibly even useful!

1986 - 1996

In 1986 I returned to the University of Nottingham as Professor of Production Management. This was a time of major expansion of the department and much time was spent on applying for funds, staff selection, interviewing, etc. It was also a time of major administrative changes in the university. I was Head of Department from 1988 until 1991, by which time there were more than twenty academic staff. In research terms I changed direction slightly away from the software development that had focussed on specific industrial engineering problems towards examining ways in which some of the themes that had recurred during the rather diverse applications outlined above could be helped by academic studies. These themes included planning and control, management information, systems analysis and design, the effect of people and randomness on performance and the fine line between success and failure. The work included attempts to develop a framework for production management and to produce some deliberately prototype software called UNISON (University of Nottingham software based on nets) to help the investigations. Some work was also done on learning curves. Some of these topics are now briefly described.

The framework for production management

The framework for production management is an attempt to describe the commonality between different production planning and control systems. The first feature it recognises is that planning and control is hierarchical. In general, plans are made in broad terms for some time into the future, then more detailed plans are made for a shorter planning horizon and very detailed plans are made for an even shorter time horizon. The set of production planning activities known as master scheduling, requirements planning and short term scheduling illustrate this progressive detailing. The second aspect of planning and control is that management information systems (MIS) are a common basis of control. Transaction data is obtained by recording the operations that are performed in the company such as ordering material, machining parts, work moves and stock issues. These transaction data are used to maintain records but they are used also to compare what has happened with the detailed short term schedules i.e. what was planned to happen. The transaction data are also summarised, perhaps weekly, and compared with the requirements plans and are summarised further, perhaps every four weeks, to compare overall performance with the master schedules. The third aspect of planning and control is that proposed plans may be (should be?) simulated to determine their expected performance and, if necessary, adjusted. These planning and control steps may be represented as in Figure 1. Each box may be considered as a black box and each line as information transmission showing e.g. inputs, outputs and feedback. This format is compatible with most system charting procedures, with input output analysis and also with control system representations for say analysis by Laplace Transforms or z-transforms. This is discussed further in the Appendices on Systems Analysis and on Production Control.

Figure 1 A framework for production management (about here)

UNISON Petri net software for systems analysis and design
The UNISON software used Petri net ideas to represent complex systems dynamically and hierarchically. It was difficult to obtain external funding for the work but we persevered on a self funded basis to investigate a range of problems that included:

- developing a structure for enterprise integration
- developing the framework for production management (see above)
- examining the conditions under which ‘push’ and ‘pull’ production control systems were appropriate
- examining ways to parameterise systems so as to be able to evolve from one system to another simply by changing parameters. In principle at least this should allow new PPC systems to be prototyped without having to completely reprogram their control systems.
- examining time based parameters e.g. different planning horizons and dealing with these within the same system structure.

Some of this work is elaborated in Appendix 2.

Learning Curves
A learning curve is a way to represent how progressively less time is needed to produce something as experience is gained. From 1989 -1993 I supervised a part time PhD student, Mohamad Jaber, examining learning curves. Until this research, my only experience with learning curves had been acquired at de Havilland when I was asked to negotiate prices for missiles with the Ministry. Learning curves, which had originated in the aircraft industry (ref), proved to be a useful basis for agreeing the appropriate prices for the next year’s production, especially as the calculated price using learning curves turned out to lie between the company’s and the Ministry’s figures. In the field of inventory research, it is clear that reducing cost/production times should affect the batch sizes and Mohamad Jaber applied learning curves to decide inventory batch sizes taking account of learning and forgetting. He has since investigated a wide range of other problems and we have published a range of joint papers. Our work together has continued, particularly on environmental matters. This is discussed later.

Post retirement activities 1996 – date
I formally retired in 1996. This allowed me to drop my administrative load. However, I continued teaching for 1 year and since then I have continued to be actively involved in research. Soon after retirement, a grant application that had been submitted a long time

previously to the EU funded BRITE Euram scheme, was announced as successful. The project called IDEA brought together organisations from the UK, Ireland, Germany, and Sweden and the emphasis of the project was on health and safety of human centred work. The project overlapped much of the field that AUTOMAT, NULISP and SAMMIE had covered but by now the available computer power was sufficient for systems to be much more integrated. I acted as consultant with the University of Nottingham team. One of our investigations within the project used structured analysis to represent the stages of product design and manufacture from requirements specification, through product design to system design and implementation and within that to create operation sequences i.e. to illustrate automated creation of methods and times as had been done in AUTOMAT. Since then we have used the structured analysis approach as a way to determine research and implementation agendas for manufacturing and research organisations and to develop the Activity Matrix concept described below.

Also in my first year of retirement I became one of a small university team of 3 that was employed on a contract awarded to the University of Nottingham by the Overseas Development Administration to restructure the courses of the Industrial Engineering Dept of the Technical University of Sofia (TUS) to fit in with the changing educational requirements of eastern European countries as they moved to more western systems. The aim was to split the TUS course into an undergraduate and a master's course so that the undergraduate course could be accredited for EU approval. Because of our familiarity with their accreditation procedures, we chose to seek course approval by the UK Institution of Electrical Engineers. Relationships with the Bulgarians were good and accreditation was successfully achieved. A trivial but interesting spreadsheet tool was developed on a laptop that allowed the course planning to consider modularisation requirements and the time and staff constraints imposed by the Bulgarian Ministry of Education and Science. Many possible structures could be considered per day. This simple interactive approach would have been very difficult in the early days of computing. Various aspects of the project are discussed in (ref). There were very few computers in the TUS at that time but in the same building there were some well equipped EU provisioned computer laboratories. One of these was using the web as the basis of running simulation classes allowing unlimited numbers of students to work at their own pace, an approach that was relatively unusual at that time but now commonplace.

In 2000, we received World Bank funding for another Bulgarian project to set up a competitive bidding process for Higher Education institutions to apply for research funds. Although related to a partial restructuring of the Bulgarian Higher Education System, the activities were pretty focussed. However, the work was also part of a much wider project potentially restructuring the whole Bulgarian educational system. The Higher Education investigation was successful in the sense that all the agreed sub-tasks were achieved but, for a whole raft of reasons, which included party political problems (3 Ministers of Higher Education), management problems (3 project directors) and difficulties at the Ministry of Education and Science related to payment of funds, it was clear that the major aims were not going to be achieved. Our part of the project did not move on to stage 2. Most other parts of the wider overall project (in which we were not involved!) did not even start. Some of the systems issues that the project raised were considered from the viewpoint of the Soft Systems methodology and presented at INTED (ref).

After retirement, I continued to work with Dr Jaber on learning curves, initially to extend the inventory investigations that had been undertaken as part of his successful PhD but since then his work has continually broadened and Professor Jaber and his team in Canada are now acknowledged as major contributors to the field of learning curves. Our collaboration also broadened; initially to consider whether production and inventory systems and logistics systems could make a contribution to environmental problems e.g. by considering the location of factories and stores, resource usage including waste and pollution but more recently into wider environmental studies. (ref) Part of this work has converted the Activity Matrices mentioned in the next section, into a form suitable for input output analysis in the Leontief sense and so made them available for analysing economic and environmental problems as has been done by several workers but nevertheless useful for our continuing work. (Ref)

The Activity Matrix

When Dr Flavio Fernandez, a Brazilian visitor to the University of Nottingham, returned to the University of Sao Carlos in Brazil, he asked me to present some seminars there on the structure of production planning and control. Preparing for this encouraged me to combine some of the structured analysis ideas from the IDEA project with my previous production control experience. From this arose my first attempt to construct an Activity Matrix (AM) to show the relations between the activities undertaken in a company and the system attributes of the company. The horizontal axis of the Activity Matrix showed the stages in producing a product, the vertical axis showed the attributes being considered and the cells showed the activities of the manufacturing or logistics system. This AM was used in a preliminary way to see whether it could be used to develop research agendas for production planning and control (ref). Some further uses of Activity Matrices are discussed below.

The Activity Matrix ideas are currently being extended to consider further how to develop research agendas for production planning and control and environmental problems. A paper discussing the methodology is being presented later in 2012 (ref) The Activity Matrix appears to have potential to become another systems design tool. The methodology to create research agendas using the AM has five successive steps, which successively derive the Activity Matrix, the Problem Matrix, the Tentative Research Matrix, the Research Matrix (RM), and the Research Agenda (RA).

AM=>PM=>TRM=>RM=>RA

Some observations

When working at Lostock, I remember being influenced by reading John Diebold, later known as the 'father of automation' because he included information processing as part of automation whereas previously automation had been a concept solely related to hardware. Diebold advocated integration. Later, at Manchester Business School from 1973?, Enid

Mumford investigated the human and organisational impacts of computer based systems. In a later paper (ref) she suggested that improving systems practice in the 1960s and 1970s gave way in the 1980s and 1990s to a harsher economic climate. Both at the time and in retrospect I think that the LEO Computers' requirement that the first application on the computer must work before the computer was installed looks very sensible. Maybe this is because it was an incentive to the seller and the potential user to use their best endeavours to achieve success and for management and the workforce to examine what they were trying to do, avoid the worst conflicts and mistakes, and to participate and solve outstanding socio-technical problems.

The work with the INTERNET production scheduling working party showed that using plug in software packages was not generally as successful as using software produced to a company's own requirements specification. Packages for PC have been available since the late 1960's but it seems that unless customised (after a proper systems analysis!) to meet the specific needs of that company, they are unlikely to meet these needs by chance and there will be much disappointment. Currently, mistakes of these early types still appear to be being made, only more expensively. Pressure to install one of the major software packages such as SAP that link together financial control and production control is great. Their commercial success is astounding but unless they have sufficient flexibility to meet the needs of a company <u>and</u> the company uses this flexibility appropriately <u>and</u> all aspects are supported fully by the software company, problems will continue. At the same time in an interesting parallel development many customised software systems are now being produced. In one sense this is a return to the 1960's but it is a very expensive and possibly even riskier solution unless there is proper system design, checking, implementing, operating, monitoring and maintaining. This is because some of these systems are socio-technical systems that are orders of magnitude more complex than the missile systems and production control systems described earlier. For example, health service information systems or police and security information systems are complex in their own right but also they impinge potentially on everyone's personal data and security. Hacking skills and possibly state sanctioned access suggest that privacy, as we know it, will change. However, none of this appears to solve the problem that has been discussed. We are left with limited, relatively inflexible packages or very extensive, expensive and possibly unreliable systems whereas we need nuanced systems with the advantages of mass production. This suggests that the mind set that produced group technology and cell manufacture and enterprise integration needs to be applied to systems software.

Conjecturally, we need to create software that can be easily personalised and to do this we probably need frameworks that enable us to define the structure of the specific system that we are designing and software that can be generated from the systems requirements specification. It is likely that this will need the full panoply of analysis and design, including simulation, experimentation and a willingness to work with ongoing change. About the only thing we can be certain of is that management by edict is unlikely to be the best method for introducing such systems. We need to be able to personalise agreed standard frameworks.

Even when using the simplified production control models described in the next section it is clear that the problem of production control is NP hard. However, as will have been recognised by the descriptions that have been made, reality is of much greater complexity than any mathematical formulation of some aspects of production control because, within real production control, there exists the interplay of political, social and technical problems. This was clear from the superficial descriptions of some of the problems at de Havilland, Renold, Raleigh, GEC and the surveys. At a technical level, production control may be NP hard, though there may be serviceable heuristics, but at the socio-technical level the problem is often indeterminate i.e. there are many ‘workable’ answers but none that will completely satisfy the ‘customer’. It was suggested with respect to the relatively technical analysis and design problem at de Havilland, that systems analysis should be seen as an experimental and not a pre-determined craft. Even more so is this true when the problems are heavily ‘people problems’. Probably the only workable solution is for the team- and the team should include the managers in addition to the systems technicians – to immerse themselves within the problem i.e. the team become part of the system. It is action research. Using action research, the systems analysis and design would reflect the views of the systems personnel, the designers as well as the operational personnel and other users.

External consultants have their uses for introducing new ideas, determining the stages involved when introducing new systems and helping to avoid other obvious implementation problems. However, they need to be used in conjunction with involved management who treat the technical and the people problems as complementary and equally important parts of the system, and who set a clear specification and context within which the consultant is to work. Above all, the managers need to remain involved. One of my more Interesting and exacting assignments was to be employed by a manager (as a consultant!) to review and criticise another consultant’s proposals and to list questions that the manager should ask about the proposals where more information, interpretation or clarification was required. This manager recognised his limitations but wanted to stay involved.

Systems

Developing the above comments about production control, it appears that industry is still not fully aware of the complexity of systems, how necessary it is to be able to deal with this complexity and how the human mind is remarkable at working with logically contradictory sets of information. To live with and thrive in this complex world, managers and engineers need to be better trained as information engineers. Currently, we appear to install and operate systems without the reliability or the back up that we demand from (say) our transport systems. Indeed, this again raises the question of how much should be handed over to the computer. For example, when, for safety considerations should we allow humans to take over and, if we do, then how do we train these operational personnel to respond appropriately to the different ways that safety critical systems could (hopefully only very rarely) malfunction. It is probably more accurate to say that new systems will not suffer from human error or computer error – just different kinds of system error e.g. a failure to have appropriate back up, a failure to train appropriately or a failure to simulate or a failure to appreciate even that there is a potential risk in a particular respect or, even more likely that because of the complexity, not every situation has been thought of, included and tested.

Why do so many large system projects fail? Among the many factors are complexity and the implications of complexity. Complexity can be of different kinds e.g. the technical problems at de Havilland and the logical complexity of relatively routine systems in Renold that involved such a breadth of applications. One problem is that we continue to underestimate the difficulty of designing, testing, implementing, and operating large systems that require the co-ordination of many personnel. We allow insufficient time for decision making and even then hurry the implementation. In many situations there is a fine line between success and failure and then the effect of people, the management structures and randomness have on performance can be crucial.

Systems management

My experience suggests that to be successful, a manager in charge of a project, whatever his original discipline, needs an engineering attitude i.e. a commitment to make the system work. In addition to designing the new computer system to be suitable for its users, there is usually a need to invest in people, for training, for piloting, for revising, for implementing and then for bedding in the system. Maintaining the motivation of such a system led group is essential. We would not attempt to send someone to the moon, or to introduce a new model of a car using the level of planning that many companies use to introduce their own specific but more complex computer based socio-technical systems.

So how can one improve performance? Simplistically, the obvious answer is to do what is required and the suggestion in this note has been that what is required can only be found by appropriate systems analysis and design. Having analysed the current system, the steps required to change a system from the 'is' to the 'what should be' are to simulate the operation of the proposed system design both manually and in computer terms in order to:

- Decide what should be
- Plan the work appropriately with respect to resources including time
- Pilot the work
- Implement the system
- Train all relevant personnel appropriately

It is worth asking whether UK management at the highest level really understands and cares about the kinds of problem that have been discussed. If not, is this just a UK problem or is it more general, perhaps international? It is doubtful of course whether any generalisation from my limited experience is valid. Nevertheless, it is fun to try to interpret the mish-mash of impressions that I have formed over the years that at the time seemed meaningful but probably signify little. The next paragraph therefore is a selection of actions, conjectures and prejudices.

At meetings the Germans appeared more structured but less pragmatic or flexible when faced with great uncertainties. On the other hand they were more enthusiastic about Industrial Dynamics than any UK manager that I have met. Superficially, the US executives and academics that I met were more immediately enthusiastic about possible problem formulations than the typical UK manager but whe n it came to implementation generally they took a narrower more focussed view of problems than their British counterparts. Over the time (1967-1984) of the university projects that I have described, we seemed to be able to get closer to the market than my US counterparts both in terms of funding and in terms of obtaining cooperation from companies. *[Note. This appeared to change adversely in my later years when the criteria for awarding grants were amended so that it became necessary to define the deliverables before starting the work. Also one was going to be judged on the success in achieving the targets. The only foolproof approach to obtain grants in this situation is to apply for work that had already been done or was so close to work that had been done that the chance of not meeting the deliverables targets was small] There appeared to be contradictory criteria that required the work to be research but for it to be judged on development criteria. I am in favour of being as realistic as one possible but if it really is research, then a much more evolutionary approach is necessary. Interestingly, the nearest we got to this was with NRDC with whom we had quarterly meetings at which we discussed progress and our proposals for the next 3 months which needed to be justified but could revise priorities in the light of success or failure or new market knowledge.].* Financial support for projects with commercial potential was difficult and continues to be a problem. On the other hand, technology transfer appears to be much better managed in the US than in the UK. Another interesting interaction occurred when discussing robot systems with the Japanese. In this specific case it seemed to be more important for them to form a collective view than to discuss the detailed technology. And so on!

Cooperation is always difficult but is the verbal directness and renowned individuality of the British a help or a hindrance in the computer world that currently we are in? Cooperation seems to depend on one-to-one contacts and trust. Yet virtually everyone is seeking to obtain and then maximise their funding and is either resentful when what they know is worthwhile is not funded whereas elsewhere people are smiling because they have successfully 'played the system'.

I was fortunate during my working career to have had managers and people working for me who in general were polite, interested, intelligent, etc. but we were also a set of individuals working within the constraints of time, resources, finance, and organisational support or hindrance of a system and culture. I suspect that this is the common state and that what is likely is that independent of nationality, most people at the operational level are trying to do their best. We need to set goals but then to give people their heads, to encourage, to review and to allow time for contemplation. In short I suspect that it is the systems that we create and the confidence acquired from past successes that are the major influence on the national characteristics and on the probability of success of new ventures.

Implications and conjectures

To participate in the field of computing fairly early meant doing things that no one had done before. Everything was new. Algorithms for exact solutions, even if available, needed to be written so that the computer could use them. More frequently, algorithms were not available and even if they were then the computer technology in terms of speed, capacity and reliability would not allow the solutions to be obtained. This encouraged the use of heuristics (effectively computational common sense or methods that are likely, but are not guaranteed to, provide a good solution). At the same time the computer showed the potential advantages of integration. For a system to do even simple tasks the logical connections had to be right even when, as was quite common, the complexity of the individual parts of the system were not fully understood. Hence, sometimes the results, or more likely the partial results, were passed over to a human planner or decision maker to use and then re-enter the consequences. That is a clumsy approach but call it interactive working or creating a (non-designed) human computer interface and it sounds much better! However, as understanding grows it is natural to attempt to make the system fully computerised. However, this changes the information flows, the organisation, some responsibilities and possibly other factors such as flexibility. Certainly an integrated system requires more discipline to design the data systems and to provide the data, although after that has been done more of the processing will be internal to the extended system and this almost certainly will lead to more top down solutions (see Appendix 2). Have we really understood what the people were doing in addition to their procedural role?

Returning again to the problems of production planning and control that were the focus of several of my jobs and of several research projects, it is clear that production planning and control is a complex man machine interaction problem that operates in several dimensions. These dimensions include: a planning and control dimension, a manufacturing dimension, an organisational and people dimension and the provision of data. Computerised production planning and control sets more stringent requirements on the accuracy of bills of material data, on operation data and on the links with design and forecasting and also because production planning and control determines how most of a company's working capital is used and provides most of the data needed for financial planning and control. Moreover, whatever algorithms are used, the company still needs to know how a product is made, the levels of stocks that are held and the items that are on order or being produced. Although, the broad relationship between the many modules that go to make up the production procedures is broadly understood and has been from the earliest attempts to computerise various parts of the system, the subtlety of the relationships between the modules and how the data is used will differ from product to product, from company to company and from demand pattern to demand pattern. Many other factors are also involved and it is this complexity, some of which may be unnecessary, that suggests that better methods of systems analysis and design are needed. Almost certainly this is true when trying to replace a system that over the years has used a great deal of discretion in the planning and operation of systems. Should we design systems that allow the operators to retain some discretion as we tried to do with the Renold scheduling system? If so, the question is how much human judgement, an attribute that a computer does not have, should be incorporated? Now that there is the computer power to design and operate integrated systems that have many interactions, this issue should have a higher priority and allow the potential implications of the discretion to be examined at the design stage. Aspects of systems analysis and design are discussed further in Appendix 2 and production planning and control is described in more detail in Appendix 3.

In the early days of computing a common difficulty was to obtain and maintain data. Many of the problems related to this appear to have been solved by the use of on line data entry. This is a great advantage of interactive working and so we were fortunate at Nottingham that over the years the interactive computing facility was steadily upgraded e.g. in the second half of the 1980's the SERC set up a national interactive computer network and, what had been our research computer then became our Departmental Computer and was then further upgraded to become one of the nodes of the national network. The development of computer aided design means that data could be captured at source and that the 'same' data could be made available for design and for manufacture. Another advantage is that computer aided methods, particularly graphic methods, allow the user to interpret various options rather than attempting to produce optimal solutions. This may provide a greater chance of success especially at the prototyping stage but it could also lead to an intuitive feel about what level of discretion should be planned for.

In the discussion to now, nothing has been said about service operations, yet they have become a progressively more important part of our economic activity, especially now that in many situations we deliberately subcontract much manufacturing work. For a variety of reasons we have lost much of our manufacturing. Although service operations lack the clear need to schedule materials through a machine shop, service operations are almost certainly as complex, and in general are more diffuse and more likely to lack clear objectives and focus. I do not know whether they are likely to display more complex social issues nor whether they are more susceptible to organisational and social problems but it is reasonable to conjecture that computerised systems in service operation will raise as diverse a range of problems as has the control of manufacture.

Commercialisation

An interesting aside is that despite the difficulty of eventual commercialisation, I think that the work on SAMMIE, AUTOMAT and GRASP (described in more detail in Appendix 1) could be viewed as an interesting study in unsystematic but successful systems analysis. It was an iterative design and evaluation process. Basically the process was that, after considerable thought about the problems that we wanted to know about and hopefully solve, we produced a first (rough) system prototype and used the associated graphics output as the basis of discussion that led to progressive system improvement and to the solution of more realistic problems in companies. We remained flexible and willing to restructure again and again so that we could solve the problems that the market wanted to be solved but in a more and more general way until we had something that functionally was quite good. Then it was restructured and rewritten.

At a certain stage of development, the problem became what to do with the packages. As SERC had provided most of the funding, we were required to offer any products that had been produced to NRDC/BTG for exploitation. However, there were still difficulties. After the assignment process there were revenue sharing arrangements to agree. With AUTOMAT and NULISP we had excellent initial support from NRDC in the form of a development contract with regular discussion to help select development priorities. We were encouraged also to do some early marketing ourselves and found ourselves on an exponential growth of sales. However the scale of the sales did not fit the market plan of NRDC and we were forced into a shot gun marriage with a consulting company that ended in disaster with financial losses to the University and a court case in which the owner of the company was convicted of fraud.

Possibly as a consequence of that experience, NRDC/BTG realised that marketing university produced software raised new problems and, as a result they created a wholly owned subsidiary, Compeda Ltd, to exploit such software. Licences for AUTOMAT, NULISP, COMPUTE and SAMMIE were assigned to Compeda. Unfortunately, Compeda was not successful and the company was eventually sold to PRIME computers for a nominal sum, with SAMMIE being one of the few packages in which PRIME was interested. PRIME marketed the package, mainly to the US aerospace industry but later moved out of the market. Soon after that we formed our own company, SAMMIE CAD Ltd.

By 1983/4 we were considering the market for GRASP and we were interested in examining the options for exploiting the software. The options appeared to be:

1. Form a University Company
2. License the software for use by another organisation
3. Form our own company

The University Business Manager was sympathetic about the idea of a launching a University Company. However, at that time university structures and funding were not good for providing financial support. This changed later. With option 2, we found that British management wanted a virtually risk free investment and could think of investment and opportunities only in short term cash flow terms. We were unable to find investment companies that had sympathy for supporting our identified need for ongoing development; essential for high tech products if they are to maintain their technological competitiveness. We therefore adopted option 3, obtained a licence from BTG and created a start up company, which we self funded. To start, the university provided some help by renting us premises on the campus and allowed us to use the departmental computer until we moved onto the newly created Science Park next to the University to become the first company located there. We felt that being on the Science Park gave us some extra credibility.

Understandably, in common with most start up companies, some problems arose with the exploitation. Although our activities were broadly successful, cash flow control took a lot of our time and sometimes forced a change of priorities that allowed survival but did not necessarily maximise long term viability.

Mechanisms for obtaining venture capital are probably somewhat easier now and there are now more sources of capital. However, I think that there is a need for more white knights to provide venture capital. For many academics options 1 and 2 would be a more appropriate exploitation route rather than attempting to become entrepreneurs.

The development and exploitation of SAMMIE, AUTOMAT and GRASP are discussed in greater detail in Appendix 1

Social Computing and other developments

It is probably appropriate to finish with a few comments about social computing and other developments in the context of what has been said so far. Over the last 57 years (i.e. since 1955), changes in computing power and the availability of tools to help with systems analysis and design have been enormous and rapid. The world is now very different. The ready availability of personal computers and 4G mobiles means that we all have immense computing and graphics power at our disposal and that most people have participated and are participating in a bottom up revolution where virtually everyone uses computers for word processing, for sending e-mails, for storing photographs, for searching for information, for reading books, and communicating in a participative sense via Skype, Facebook and Twitter. What the end result of these developments will be is still a matter for conjecture but it seems likely that they will affect newspapers, films and TV, books and libraries, the availability of knowledge and how educational institutions use these extra dimensions of possibilities. Will the lecture, as most students and lecturers have known it, die? Are we going to have progressively better produced presentations that can be accessed by any individual or institution? Are we all going to have diversified realistic experiences based on simulations and games possibly in a virtual world? If so then how do we ensure that ethical considerations are part of the mix, particularly if the old fashioned influences of family, teachers, friends and managers are likely to be diluted? Even if only a small proportion of the possibilities materialise then what will be the role of higher education? Alongside this there are broader issues. Society will change in unknown ways as it always has but, on top of that, social networking is likely to change attitudes that will impinge on virtually all issues. A more subtle change could be the interaction between defined systems; the classic applications software beloved by system designers and programmers and the flexibility that people have got used to e.g. related to games that can crash without too much worry or choice of film that can also crash. How defined must we be and how much control must we hand over to intelligent systems as is progressively happening with traffic control and, very important, how do we maintain and develop ethical considerations? Will they be accepted willingly or will another dimension of sanctions be needed?????????

Acknowledgements
I met Frank Land, previously of LEO Computers Ltd and subsequently a Professor at LSE, when I was working at de Havilland and again when I was at Renold Chains Ltd. In 2011 we met again after almost 50 years. Over a very pleasant lunch he expressed an interest in my reminiscences and this rather rambling stroll down memory lane is the result. This has been interesting for me but not necessarily what is required. My memory has not always been reliable and in some places I have found it difficult to sequence events. I apologise for the errors that remain.

References
By topic in the sequence of the note.

Draft for discussion
Maurice Bonney

May 2012

Appendix 1
Some Nottingham developed software that had market potential

Introduction
This Appendix examines the SAMMIE, AUTOMAt and GRASP projects in greater detail. These projects were undertaken at the University of Nottingham under my supervision during the period from 1967 until 1984. They were started when computer graphics facilities were primitive and there was little supporting software. The projects showed that interactive working is valuable, that there was a niche market for the software that was created, that in principle the products could be part of an integrated system and that there was great difficulty to obtain venture capital to form start up companies or to get companies to take over the products for marketing. Eventually, we marketed the products ourselves. The problems of commercialisation were discussed at the end of the main section of the note on experiences. The two companies that were started, BYG Systems Limited and SAMMIE CAD Ltd have survived. One is doing well.

SAMMIE
The original inspiration for SAMMIE was a student project looking at fishing rod design, which we immediately saw as an example of a man machine system – the rod would not catch many fish without a fisherman! The fishing rod provided an interesting example to see whether the analysis, modelling, experimental testing, and reality approach used at de Havilland and mentioned in the description of my work on missile design, would be useful. We conceived the SAMMIE project as a general simulation tool for work place and work task design using interactive computer graphics; hence the name System for Aiding Man Machine Interaction Evaluation, a name that was friendly (almost human) but also non constraining. Dr Eric Roberts and I started the SAMMIE project as a private venture in 1967. The focus of the system was on the design of a tool that could be used for ergonomic evaluations. The idea was that a computer model of a man could be combined with computer models of the workplace and of the equipment that was being used. We thought that there were many design problems for which designers and their contractors did not have sufficient knowledge to use optimised design procedures and which we believed would be helped by <u>seeing</u> what was being done or being proposed in addition to any quantitative evaluations that were undertaken. The 3 parts to the project were:

- To develop a man model,
- To develop a 3D CAD system to allow us to model workplaces, e.g. kitchens, aircraft cockpits or various other kinds of cabin
- To consider the design process including defining the workplace, stating the task to be performed by means of a work task language, and evaluating the simulated work that the man model was performing.

In order to start the work Dr Roberts, another colleague and I undertook some consultancy. We then used our earnings to employ Dave Evershed as a research assistant to develop a computerised man model. Dr Roberts left to go to Churchill College, Cambridge in 1968 and I continued to manage the development of the very embryonic SAMMIE system.

The initial 'man model' started as a 2 link stick man, i.e. two connected vectors that were used to represent the upper and lower arm. The positioning of the arm was determined by selecting angles using some extremely approximate 'natural planes' data, derived by a small number of us sitting in our research room and waving our arms about to determine approximately where our elbows would be if our wrists needed to be in a particular location. The results derived by the computer model were drawn on a graph plotter attached to the university KDF 9. Many people became interested in the project. Indeed for some time the project appeared to have a life of its own and a common greeting from other academics and administrators at the University was 'How is SAMMIE today?' With our appetites whetted we wanted to test our ideas using better graphics facilities and as soon as I had some demonstrable results I sounded out SRC about possibilities. Having been advised by SRC that the project on its own would not justify major funding, I submitted an application on behalf of the Faculty of Engineering (at that time called Applied Science) for computer graphics facilities to tackle a range of applications. Not surprisingly it was not successful but I think that it helped us obtain a small grant to use the Warwick University computer (see below).

I cannot remember how we persuaded them but the next stage was to use the Elliot interactive computer graphics facility at the National Physical Laboratory at Teddington by borrowing time at weekends from Friday afternoon to Sunday lunch, with the work lightened occasionally by attending a jazz session late on Saturday nights at a local pub. After about a year working at NPL like this with very antisocial hours, we obtained a small grant from the SRC to hire time on the Elliott computer at Warwick University on midweek evenings (based on a previous de Havilland contact with Prof Buxton). Using this resource, we developed a flexibly dimensioned man model with 2 arms, 2 legs, a spine, a head and primitive flesh modelling and a 3d graphics modelling system. In 1974, these primitive components allowed us to demonstrate the potential of the project and I obtained a large grant covering the period 1974 -1979 to support a team of 5 researchers and to obtain our own computer, a PRIME 300, linked to Tektronix and IMLAC computer graphics. The aim was to redesign the prototype SAMMIE system in order to create a system that could be used to solve practical design problems.

In the prototype system, the man model had been produced by Dr Evershed and Dr Case, and the workplace model by Dr Hughes. It was hoped that the initial evaluation process would among other things include work study evaluations (see AUTOMAT below). When the software was restructured, further facilities were added to enable us to display what the man model could 'see'. Vision facilities included monocular and binocular vision, fish eye views, and reflected vision to allow us to evaluate mirror designs for the motor industry. Various graphical representations such as visibility charts, identifying where vision was blocked, etc. were also produced. By choosing the limb lengths and the angular constraints on the linkages of the man model, SAMMIE could calculate reach characteristics for any given dimensioned man model. Note that by now we had moved away from 'natural planes' to a more formalised system of angular constraints. Euler angles were used for the 3D angular representation so that in principle we could include limb moments of inertia in the models and would be useful for developing better modelling of the spine.

Many applications were undertaken; the line of sight routines were useful for a fork lift truck design project, the vision routines were used to help to design the lighting system for an airport apron, reach, posture and vision were used to evaluate the check-out design for a major retailer, reflected vision routines were helpful for mirror design studies, roof support systems were examined for the National Coal Board and reach contours were calculated that would become the basis of a British Standard for tractors. Earning money for some of these applications enabled us to enhance the facilities by employing additional research assistants. Also the work ensured that the software remained straightforward to use for practical applications.

Neil Kennedy, our main computer scientist, produced excellent software and in particular, the novel graphics and associated data structures, were developed in house because at that time there were no commercially available alternatives. Designing for speed of response was very important because of the limited capabilities of the PRIME 300 and the large number of calculation involved. Many detailed contributions were made by other researchers, particularly Keith Case and Chris Blunsden, e.g. flesh modelling was improved and some early hidden lines algorithms were included. An associated study was performed by Patrick Purcell of the Royal College of Art under the direction of Professor Bruce Archer, with the aim to evaluate the SAMMIE project for usability. Perhaps this was a little premature because towards the end of our major funding it had been planned for the emphasis of our work to become more applications oriented. The evaluations were undertaken particularly by Dr Case and Dr Porter.

Probably in 1979, after some very difficult negotiations, the software became the property of the BTG software subsidiary, COMPEDA Ltd. The negotiations included agreeing appropriate revenue sharing arrangements between BTG, the University of Nottingham and the researchers, who were the owners of the intellectual property rights. The research team retained the right to use SAMMIE and this enabled a reduced size group at Nottingham, partly funded by COMPEDA, continued to add functionality to the software and to use this developing software for applications. COMPEDA was more interested in having a compatible set of software products. Later, COMPEDA was taken over by PRIME CAD Ltd, who licensed the software for use by many US aerospace companies but compatibility issues made our new functionality difficult to integrate.

Eventually, PRIME moved out of the CAD field. In 1984, three of the team who had been involved in the earlier developments; Dr Case, Dr Porter and I, all now employed by Loughborough University of Technology, formed SAMMIE CAD Ltd to exploit the software commercially. The company still exists and is located on the Loughborough University campus.

A pleasing recognition of the innovative aspects and the practicality of the SAMMIE software came later with the group being awarded The Otto Edholm prize by the Ergonomics Society in ( ) Descriptions of the project and the field of man modelling will be found in (…) Another implicit recognition of the work was that Keith Case and Mark Porter soon became professors.

AUTOMAT

AUTOMAT (AUTOmatic Methods and Times) was a separate but linked project, which started in 1968 and was developed over the period 1968-71 by Dr Norman Schofield as part of his PhD research. Later, Dr Schofield was employed as a post doctoral research assistant, and financial support was obtained, initially from SRC from 1971 and later from NRDC until 1974, to employ him and a further two research assistants to undertake the software development and testing the ideas. The aim of the investigation was to examine whether it was possible to partially automate the process of work study. The investigation examined whether it was possible to develop standard times for a task by using a computer, which would be provided with a high level description of a task (discussed in more general terms later), information about the location of the operator, and information about the parts (weight, size, handling characteristics, etc.) and the tools that were being used, and their location in the workplace.

For me, a strong motivation for developing a computer aided work study system was that the work at de Havilland and at Renold had shown the difficulty of obtaining production data and that was a need to be able to generate production data such as operation times automatically. Another motivation of course was to contribute to evaluating any proposed workplace design by examining how the work content of a job changed as the location of the operator, the workplace and the task changed; in other words, potentially it was a tool for evaluating (simulating) various production arrangements. AUTOMAT was linked initially with SAMMIE in order to determine the time that a man would take to carry out a task at the work place. These times were developed operation by operation on the computer graphics screen as the SAMMIE stick man model performed the designated task. One thing that the displayed stick man showed was that the arm position algorithms based on the natural planes data produced rather discontinuous man model arm movements and this was one reason for developing more sophisticated algorithms later.

To progress the project and to assess its relevance, all of the team trained to become MTM work study practitioners. However, because of the then current limitations of computer power, AUTOMAT was later separated from SAMMIE to become a stand-alone computer aided but not graphical method for generating methods and times and performing work study evaluations. One reason for separating was that the validity of using work study for ergonomic assessments was questionable because of the averaging processes used in the generation of the MTM data. Nevertheless, in the hands of a knowledgeable analyst, I think that the facility could have provided another approximate way to evaluate the work being performed. However, a more important reason was that the focus of the two systems was different; SAMMIE essentially focussed on design whereas AUTOMAT was mainly concerned with human production operations and this meant that their developmental priorities were somewhat different.

MTM (Methods Time Measurement) is a set of work study tools that can be used to represent work in terms of its constituent work elements, perform work study analyses and hence, when appropriate, help to redesign work by using the analyses to improve the methods used. The work study analysis of AUTOMAT also identified long reach tasks and calculated statistics related to the balance of work between the left and right hands and whether there was a high proportion of fine work versus straightforward pick and place operations. Because MTM standards are not universally used, it was necessary also for AUTOMAT to be able to use company standards, however derived, instead of or in addition to MTM standards. This problem was solved by designing AUTOMAT so that macros could be built that could be used alone or in combination with any other work study system.

Support, particularly for contacts and conference presentations in the USA and in Sweden, was generously provided by the MTM Association. Having the support of a professional group helped us to meet relevant researchers and executives from other organisations and for our project to be accepted generally by the work study community research ensured, indeed required, considerable independence. A lengthy article in the Financial Times also gave us credibility and we soon found ourselves in the business of providing short courses. Appropriate descriptions of the AUTOMAT can be found in ….

Once operation times for manual work could be derived automatically there was an obvious need to extend the work to calculate times for associated machine operations, etc. And so the COMPUTE software was developed as a way to generate times for machine operations and for warehousing operations. An interesting feature of AUTOMAT was the production of heuristic workplace layout routines that would automatically position tools and parts in a workplace so as to minimise the distance travelled, balance the work between the two hands and to position parts that needed tools near to the left hand so that the right hand could use the tool, etc. In common with most of our developments, the system was designed so that the rules operated around the planners requirements e.g. so that you could ask for 'all parts to be laid out except for …' i.e. the planner could fix as little or as much as he wished and could modify it later. The use of jigs and fixtures and standard workplaces was thus encouraged. The process was iterative and interactive. All of the software facilities were evaluated on company applications.

Another interesting evaluation was to use the computer to analyse a particular task, and then to get them typed in the same format as a MTM analysis of the same work performed manually by an instructor level MTM practitioner. Both sets of results were then submitted to a range of other experienced analysts to see whether they were able to identify which analysis had been performed by the computer and which by the skilled practitioner. Within the limitations of the examples and the people used, no difference was identified between the human and computer derived analyses. We did this simple Turing Test mainly for our reassurance. In my opinion the work study analysis was simple AI but this view was not popular with the few AI practitioners to whom it was mentioned because the work did not use accepted AI software. [note that a similar reaction occurred some years later when our GRASP robot simulation software (see below), produced usable routines for robot tool path control and for off line programming.] When using heuristic methods to generate results, our cheeky assessment was that the main requirements were; that the results are usable, secondly check that the results were not biased and thirdly ensure that the system does not produce ridiculous results e.g. a robot path that goes through another object. If standard AI software was helpful or more efficient then by all means use it but if a simpler approach could be used to achieve the result then why not use it?

Having produced a system that could derive methods and times automatically provided an incentive to develop the NULISP (Nottingham University Line Sequencing Program) software further. NULISP was originally started as a student undergraduate project but was later extended and evaluated by Dr Schofield and his team with NRDC support. Again using heuristic methods, NULISP could analyse a wide range of assembly line design problems including mixed model assembly lines. Applications ranged from a simple problem of filling pill bottles, to designing lines for assembling lamps for the auto industry within a flexible team size working environment, to balancing caravan production lines that had personnel working both on the inside and on the outside of the caravan at the same time, etc. Literally hundreds of product lines were evaluated and the software was able to produce usable results for very complex products.

The NULISP software uses precedence diagrams to describe the logic of assembling a product in conjunction with work element times that may have been derived either manually or by AUTOMAT. From these data, NULISP could:

- either be given a specified cycle time (equivalent to specifying the required output), from which NULISP produces a balanced assembly line that minimises the number of workers required to produce the required output.
- or be given the number of operators, which NULISP would use to produce a balanced assembly line that maximises the output (equivalent to minimising the cycle time).

It was indicated above that NULISP could balance mixed model lines. An interesting aspect of mixed model line balancing is that the operation times for each model are likely to be different even when they have been planned to be produced on the same assembly line and so need to use the same planned cycle time. It is likely therefore that the total time that production takes is dependent on the sequence in which models are released onto the line. That is exactly the flowshop sequencing problem and this was a problem that one of our undergraduate students, Steve Gundry, studied as an undergraduate project in 1968 using a heuristic method called the slope matching method. The slope matching algorithm was inspired by the geometric ideas used in Palmer's slope index algorithm (ref). Gundry's work also showed the equivalence between the flowshop sequencing problem and the travelling salesman problem. Just as we were just about to present a paper about it, a paper was published elsewhere. We were 'pipped at the post' in this respect. The slope matching algorithm was the only occasion that I had the results of an undergraduate project immediately published in a high quality journal with relatively few changes (ref) although several other projects contributed considerably to investigations that were later published.

Also identified in Gundry's project were two other geometric heuristics, the slope sequencing and slack sequencing algorithms. The slope sequencing and slack sequencing algorithms, although based on logical contradictions surprisingly performed much better than the Palmer's slope index and the slope matching algorithm. The performance of these and other algorithms developed specifically for NULISP were investigated by Grant as an undergraduate project and presented in 1970 at a conference at Karlovy Vary (ref). At that time, the heuristic slope matching algorithm was considered of interest. Some 10 different heuristics were included within NULISP so that a mixed model assembly line designer could compare their usefulness for specific lines and models. Some time later the work was passed to the Dept of Theoretical Mechanics (applied mathematics), which undertook a range of student projects for many years up until about 1980. I was involved at the beginning and end of each of these projects to try to relate the work to the original context. Dr Middleton of that department later published some serious mathematical representations of stochastic versions of the problem (ref). (The dates do not appear to be consistent with the NRDC funding???). Because of NRDC's commercial interest, the specific details of the algorithms was withheld for a period and this stopped publication at that time. Some 20 years later, when computer speeds and better algorithms were available; our heuristic algorithms were not considered of interest by the academic community.

GRASP

Another major project was GRASP, a computer package for robot simulation and off line programming. GRASP (Graphical Robot Applications Simulation Package) was prototyped using robot models based on the linkage system and the graphics modelling system that had been developed within SAMMIE. The approach again used interactive computer graphics, which was particularly useful for identifying potential clashes e.g. between two or more moving robots. SAMMIE represents a person as a linkage system. It was an obvious development to try to use the same software to model a robot, a more obvious linkage based system. The work started in 1979. Our industrial partner was PERA (the Production Engineering Research Association) whose Director General was Prof Heginbotham, our previous Head of our Department and an expert in the field of robotics. At the time, I was acting Head of Department and so this was an obvious collaboration, particularly because in 1967 when we had started the SAMMIE project, Prof Heginbotham immediately had seen the potential for using the approach to model robots.

With the encouragement of the SERC Robotics initiative over the period from 1980-1984, GRASP received major research council support, the software was restructured, many other facilities added and the workability of the solutions using a library of robots that we had constructed was tested against increasingly complex industrial problems e.g. to model systems that had more than one robot, conveyors and many work places that required time co-ordination and parallel working. By this time the computers that we were using were mainly work stations and were beginning to be quite powerful.

By 1984, the Science and Engineering Research Council thought that GRASP was sufficiently advanced and robust to be self supporting and in 1984, we started a company called BYG Systems Ltd to exploit the software. BYG Systems Ltd became the first company to occupy premises on the new Science Park owned by the City of Nottingham and located next to the university with the hope that the location would encourage the formation of Technology Transfer Companies. The company was named BYG Systems Ltd, from the surnames of three members of the project team; myself, Maurice **B**onney, Dr Yoon Fat **Y**ong who had been instrumental in developing industrial applications and Dr Jon **G**reen who had developed the inverse kinematics routines, the clash detection routines, the hidden line algorithms, offline programming routines, etc. Initially, BYG concentrated on marketing the GRASP software that had been developed at the University. It then moved into developing training packages related to robotics and interactive graphics. It then moved into the development of authoring systems. Since then, the company has evolved into a successful computer based training organisation. As at 2012, the company is thriving and, against economic trends, is expanding encouragingly. GRASP, obviously having had major developments, still exists and produces effective robot workstation models and realistic graphical representations of robots operating at different work stations along a production line. It is a good simulation tool.

Appendix 2
Systems analysis and design (A lot of rewriting to do or omit????)

Overview

The main discussion asserted on several occasions that systems analysis and design methods are needed to design and implement computer and other complex systems. This Appendix discusses some system concepts and examines some of the methods that are available to help systems analysis and design.

The word 'system' is often used (overused?) to describe any complex interacting arrangement of components that are apparently purposive. In general a system exhibits properties that are difficult to infer from the individual properties of the components i.e. a system frequently displays emergent properties. We are particularly interested in systems within which computers and people are major components and of particular interest is how to determine the requirements of the system that we are defining. Obviously we would like the clerical, computer or manufacturing system to 'work' and would like also that the new system is robust. Many systems are man machine systems that we would like to produce something that is acceptable to the internal users and to the wider customers. It would be even better if the users could feel that they were part of the system, as then they would be more likely to help to make the system work and to be part of its progressive improvement.

Most human activity systems just grow, seemingly organically, until it is clear that they need major improvements. Generally, an attempt is then made to use systematic methods to investigate the problems. This investigation is called systems analysis. If it is decided to computerise some parts of the system it is usually considered to be good practice and sensible to tidy up the current methods first. Thus

Systems analysis is the process of finding out about the present situation; specifically to know what currently is being done, whether it is being done successfully and what else requires to be done?

The process of systems analysis usually starts by obtaining a general description of what is being done. This identifies the scale of the activities e.g. for a company, to obtain the turnover, profit, number of employees, the product profile, the competitors, etc. A SWOT (strengths, weaknesses, opportunities and threats) analysis will often help to identify some useful aspects about the current system and to determine what else should be done? Standard work study practice will produce travel charts, distance travelled, times taken to do things, time spent waiting, etc. When planning a new computerised information system, an emphasis is commonly placed on studying the current information flows so as to produce a 'systems chart'. A systems chart commonly shows the information flows in document terms, and how the computer uses the data provided to produce certain output 'documents'. It is often useful also to see the information flow in a broader context by examining material flows, people flows, energy use etc.

Once there is some knowledge of 'what is' then

system design tries to decide 'what should be' and how it should be achieved.

There are many ways in which people can design systems but it is not always clear what is the best way to achieve this. There are many adequate methods available to produce a good analysis and design but it is likely that we still do not have ideal systems analysis and design methods. If we do, then in general we do not fully use them. Some indications of systems analysis and design for production planning and control are made in Appendix 3

Models to describe systems

The simplest way to represent a system is as a 'black box'. The concept is that inputs go into the black box and outputs come from it and that initially, we do not know what is inside the black box. This simplistic idea that a system is a process that converts inputs into outputs is a useful way to guide questioning so as to obtain a rough understanding of what the system being studied is and what it does. For example, typical questions about inputs could be: What are the system inputs? Where and how is this (information/ material/signal) obtained? How would we like it to be used? What would we like it to produce? Similarly, typical questions about outputs could be: What is obtained from the system? What would decision makers and users like the system to obtain? What will it be used for? If so what needs to put in? How will the results be used?

The black box input-output approach has been formally structured to become a systems investigation methodology (Towill and Parnaby). Generally, it is useful to ask a set of complementary and confirmatory questions.

Symbolically, if an input to the black box is *x*, the output from the system is *y* and the conversion process is represented by *f(x),* the system may be described simplistically as *y=f(x).* This representation can represent many different situations e.g. *x* could represent material put into a machine, *f(x)* could represent the material processing performed by the machine and *y* could be the machined part that result; another situation could be that *x* could represent a sick patient, the process *f(x)* could be the treatment provided by the hospital and *y* could be the treated (hopefully cured) patient.

Although, such simplifying formulations frequently have merit but in practice it is clear that most systems are more complex. In general there will be more than one input, typically a set of inputs, a set of transformations that create the products, spend the money, produce the accounts, train the personnel that do the work, etc., and a set of outputs. In other words the system is multivariate. A multivariate system could be represented as

$$\{y\}= \{f((x)\}$$

where,
{y}=y1, y2, …. yn
{x}= x1, x2, …xm
{f}= f1, f2…fp,

Inevitably 'reality' may be worse in the sense that in many situations there may be a shortage of knowledge, data can be accurate and managers and researchers may not necessarily interpret the available data and management information correctly. In other words the real inputs could be *{x'},* the outputs could be *{y'}, and* the transformation could be {y'} = *g{x'}.* More difficult problems may arise from random effects and various unknowns, some of which may be identified and others that may be a complete surprise; the unknown unknowns.

Feedback
An important factor about the system structure that has been described above is that it is *open loop.* It was suggested earlier that systems were generally purposive but open loop systems do not check how close the results that are obtained are to a possible target. They miss a key point, namely that most systems require negative feedback to determine how they are performing relative to the targets so as to make corrections to ensure that the system performs approximately as designed. For example, when driving a car we continually check the direction in which the car is pointing and if necessary adjust the steering direction. When a room thermostat is set at a chosen room temperature of say 22C, the heating source switches off when a sensor shows the temperature arriving at the desired temperature but goes back on again when the room starts to cool. Such systems are called *servomechanisms.* They use the mechanism of *error actuated feedback control* i.e. the present value is subtracted (hence the term *negative feedback*) from the target value to find the difference. This difference (*the error*) then controls the action.

In physical equipment, electronic filters are usually part of the control system and are chosen to produce the desired time response. With human systems under management control, similar principles are used. For example if a target stock level has been set, then the computer system will check how far the actual stock level is below the desired (target) level and respond accordingly. This approach was used with the various models described earlier; when modelling the missile, when modelling production and inventory control and when using industrial dynamics simulations. Some additional comments are made about this in Appendix 3 related to production control. ??? omit

Systems need feedback to meet short term targets but also to control longer time scale plans corresponding to the other organisational planning cycles such as long term planning, budgeting, master scheduling, requirements planning, etc. Management information, performance statistics, economic data, etc. provide feedback from which new tentative plans are produced, the resource implications (and availability) of which are checked before they are converted into new company operational plans. People are frequently part of the control function in many large systems but their representation may cause some difficulties because the control function they perform may not be known because the control may depend on other subtle factors that include the politics of the situation and the motivation of the controllers.

A further complication is that information is motivating and that misinformation or misinterpretation of information can lead to poor long term planning.

Categories of System: Hard and Soft systems
Checkland suggests that there are 4 kinds of system:
…..

Of these we are primarily concerned with human activity systems.

Although there are few systems that do not depend on people, some systems are predominantly hardware and some are predominantly people. For this reason systems are often categorised as hard and soft systems:

- Hard systems are systems such as missile systems, robots, computers and computer controlled manufacturing. Hard systems are predominantly physical. Known or derivable algorithms may be used to describe their activities. The procedures to analyse and design hard systems were clearly stated by Jenkins in 1970 (ref). Even though it may be difficult to perform the procedures e.g. it is not easy to design a moon shot, they are systematic. On the other hand the performance of nominally hard systems may surprise e.g. the melt down of the Chernobyl nuclear plant was essentially a people problem. Similarly, robot safety became a (short term) major interest in 1984 (ref), when someone leapt a barrier and was killed by a robot. People can take unplanned actions and people can make mistakes.
- Soft systems ( ) are systems in which people are a major part of the system. Systems in this category include education systems, management information systems, health systems e.g. the operation of an accident and emergency unit. Checkland developed the soft systems methodology to investigate this type of system. (refs). Soft systems are highly topical and their investigation has been taken up by many researchers. (refs)

Hard and soft system investigations may be used in conjunction e.g. hard tools will help to estimate resource requirements for a particular type of organisation e.g. by using arithmetic or even sophisticated resource scheduling algorithms. Assembly line design may be considered as a hard system design problem that operates within the total factory organisation and design, which may be considered as a soft system. Also the performance of an assembly line may be greatly affected by the work organisation that is chosen. However, to determine the type of organisation that is required and will work best say for the National Health Service, a major employer undergoing rapid technological and organisational change that has many different human and political dimensions, would almost certainly gain by using a soft systems approach This illustrates another systems problem; how to choose and where to set the boundary for a system investigation.

Setting the systems boundary requires balancing the desire for integration while at the same time creating a system that is understandable to the participants on a human scale. One underlying problem is that although people in general like (need?) structures, they do not like to be constrained and in some situations will act to defeat the controls e.g. Charlie Chaplin in Modern Times. Many people feel that here is a need to live with friends and family rather than in an institution, use cell manufacture rather than have huge assembly lines with very small cycle times e.g. increase of cycle times by GM, the Kalmar group assembly experiment, etc. In summary, systems and activities need to be put on a human scale; big but perhaps not too big!

System representations

It is becoming clear that systems may be represented in many ways. Diagrammatic methods frequently use boxes connected by lines and can represent particular attributes such as data flows and storage and physical flows and storage. Standard flowcharting based on a variety of standard symbols was used from the earliest computer work (not necessarily the same by different computer groups). Inevitably the IBM standard was quite popular. A typical flowchart is shown in Figure A2.1

Figure A2.1 about here

Hierarchy is an important system characteristic. An interesting system representation is structured analysis which is a particularly well developed formalism. The developments of structured analysis and the large number of variants on the basic idea such as: SADT, IDEF0, IDEF1, .. IDEFX place the emphasis on data flows and on activities. Various researchers have extended this idea e.g. Popplewell's work on moving boxes becoming a dynamic representation/simulation of the system being investigated (ref)

An attempt was made to bring the wide diversity of systems approaches together in an EPSRC workshop on systems In /1984? Included in this were the Nicholson I page summary of systems. (Personally, I think that the 1 page Renold system description shown in Figure A2.1 is a similar idea but more focussed), Towill on his black box ideas, Checkland on his soft systems, Hindi's work, Mention others? A similar need was also identified in 2 volumes of the Journal of the OR society that were predominantly about systems issues. In 199???? the University of Nottingham organised another EPSRC workshop at Castle Donnington focussing on ??? The participants all agreed that the papers presented should be published as a book but unfortunately for that to become a useful publication it required an extensive and enlightened commentary that would have required much more time than any of us had at that time. It is still needed. (Need access to the original papers!)

This suggests a move towards using a systems representation that can automatically be converted into a simulation of that system was what we were attempting to produce with our UNISON Petri nets software that included within it ways of representing the Nottingham systems framework for production management

Input output analysis
Being dynamic is another system characteristic, Bring all the characteristics together

Etc, etc, etc

Figure A2.1

Figure A2.2

Figure A2.3

It is likely that all variants of production planning and control can be expressed by the general arrangement of material flows and information flows shown in Figure MCB should the framework for PPC also show stocks? If so then does that make the specification for UNISON better?

Appendix 3
Production planning and control

Definition and context

Production planning and control is the function that manages a company's resources of men, machines and materials so as to achieve the company's production requirements in respect of quantity, quality, cost and time in an efficient manner. Production planning and control co-ordinates many resources to do specific jobs and is a man machine system both at the planning and at the operational level. All production control systems attempt to coordinate the availability of materials so that they will be there when they are required to be used. Many tools are used to help plan and control production. Some of these are more appropriate than others in specific situations. Manufacturing companies need to produce their products efficiently and on time. To do this they need to plan and control the quantity and quality of the products, their cost and the time when they are available. In other words there is a need to produce the correct number of products of the appropriate quality and cost and have them available at the required time. The two main approaches that are used to achieve this are to:

- make to order
- make for stock and replenish the stock that is used.

Queues, product organisation and process organisation

The lack of key components can stop production. The targets that are set for completing the production of a product are usually based, directly or indirectly on customers' orders. One possibility is to make products directly to meet the customers' orders that state the required quantity and delivery date. Another possibility is to hold the product as stock and then take the items/products from stock when an order is received. The stock is then replenished (for methods see below) so that more stock will be available to satisfy future orders. The greater the product variety, the more difficult it becomes to satisfy orders directly from stock. This may be partially overcome by having a range of models available from stock e.g. 'standard', 'de luxe', 'XL', etc., a range of engine sizes, colours, etc. Variety needs to be strictly limited or planned for. Many companies have a separate organisation for 'specials'. To ensure that lead times for a customers order are not too long it is common to order some long lead time items in anticipation. However, to hold raw material, parts, assemblies or finished products stocks requires working capital. Therefore, if stocks are held, the reasons for so doing should be clear.

Over the years and particularly under the influence of the Japanese production methods the emphasis of production has changed so that Just In Time (JIT) methods have progressively replaced the more typical 'just in case' approach that previously existed. The emphasis of JIT is on eliminating all unnecessary activities and items. An attitude that 'inventory is waste' has replaced the view that inventory is an investment. JIT probably requires an even bigger change in the culture of a company than the introduction of the scheduling methods discussed later. JIT, as it is popularly understood, can only be practiced in 'pure' form by mass production industries. From Henry Ford onwards the assembly line became the traditional and efficient method of producing complex assemblies and was used to produce products such as cars, refrigerators and washing machines. Of course an assembly line can also be used to produce pork pies and fill pill bottles. However, for most engineering products, assembly lines require parts made with sufficient precision that they can be used interchangeably and still fit together. Assembly lines are a particular form of organisation called product organisation where the focus of the organisation is on the product. Typically this has the effect of keeping the elapsed time required to make something relatively short. An important characteristic of product organisation is that the location of the next operation is known e.g. it is the next station on the assembly line and so there is no need for routing instructions. Also, if a line is balanced the amount of work at each work station is the same and so there are on queues. Sometimes, even when work is not appropriate to be performed on an assembly line, product organisation is possible i.e. machines and workers are dedicated to producing a particular product or range of products or group of products.

When there is product variety such as with some pumps and motors, or when production is in low volume or when a company is producing many 'specials', then potentially every customer's product requirement is different and manufacturing is likely to use the traditional functional organisation for making the products. Functional organisation is commonly applied to the production of many products of great complexity such as products from the aerospace industry, particularly when produced in relatively small volumes such as the missile production that was discussed in the description of the work at de Havilland. For this, operations are organised into functional or process groups such as groups of lathes for turning operations, groups of milling machines, machines for presswork, plating operations, heat treatment operations, etc. In a functional organisation skilled workers may be expected to produce items that may not have had so much effort expended on planning the work, although routing instructions are important. Functional work organisation, also known as process organisation, is frequently characterised by long queues of work waiting to be processed at machines groups. The work being processed or waiting in queues is called work in progress or just WIP, although of course it would be more accurate to describe it as work NOT in progress. The lead time is the time it takes for the job to be completed including the queuing times. Because of the queuing, production lead times are often long. Also, the control of the work is more complex than with product organisation and some organisations will rely on the skills of their workers to produce something rather than have major process planning.

As always, things are not completely black (functional organisation) or white (product organisation). The demand for the products of most companies usually consists of a mixture of new and repeat orders. Companies have a competitive edge if they specialise and so many of the products that they make are similar, differing perhaps in size or in having different attachments. Hence, in practice, repetitive batch production is the commonest form of manufacture and depending on the degree of repetitiveness, and in this situation it is possible to use either functional or product organisation.

Although generally requiring a greater amount of planning, product organisation would normally be preferred to functional organisation because of the advantages of its greater simplicity, shorter lead times and less investment in WIP. Therefore, manufacturing industry has made major attempts over the years to obtain the advantages of product organisation by producing items on machines dedicated to a restricted range of items. To achieve this, group technology, cell manufacture and better materials handling are used. These are frequently used in conjunction with automated machinery such as CNC, DNC, machining centres and robots in order to produce items that have consistent quality and are made to the precision required. Sometimes these machines are used in combination to form flexible manufacturing systems (FMS) which are typically automated cell manufacture; i.e. virtually a stand alone factory within the main factory. Sometimes multi operations are performed on one machine e.g. a transfer machine to avoid the queuing and delays associated with using several individual operations and to have the advantage of a single set up.

When there is little detailed planning but there is an attempt to keep certain key resources such as men and specific machines busy, this in itself will lead to queues. Much as when driving on congested roads, the busier the roads the longer will be the delays. Queueing theory shows that with random arrivals (heap and hope) and random service (no attempt to make sure that the batches have standard amounts of work content), when the average service time is T and the average idle time proportion is p then the average queueing time is T/p. In other words, if a facility is 90% busy and on average the batch is a half a day's work, then the average queueing time is 1 week (1/2 / 0.1 = 10 half days = 1 week). Such length delays can be greatly improved by reducing the randomness including by scheduling.

Scheduling

Scheduling is the process of determining when things should be done. The set of activities to be performed and their associated times is commonly called a *schedule*. The choice of scheduling method should primarily be an economic decision that depends on the cost of the products, the volume of sales and the margins, the needs of the market (stability of demand, rate of change of product specifications, required delivery lead time, make to order v make for stock), the cost of planning and the capability of the company's management. It is common for production to be the main driver of costs within a company because of expenditure on labour, machines materials, and work in progress (a euphemism usually for work that is not in progress but is waiting in a queue for someone or something). It is logical therefore that the production planning and control procedures should be the foundation for financial planning and control and for them to provide the data that will help to determine the financial implications of production decisions.

When planning something it is logical to start from time now and to plan forward into the future. This approach is well known for project planning and control using critical path methods (also known as network analysis). Forward and backward scheduling, in combination, can identify which activities have a lot of flexible time (the concepts of slack and float), control of which can be a useful way of smoothing the load on resources. However, when there are many items to control, detailed forward and backward scheduling may incur large overheads in terms of the need for data and its availability and in the amount of computation required. As a result of this, many different approximate scheduling methods have been created and used. In general, approximate methods require less data and calculation but produce less good answers. Very simple methods to produce approximate solutions are sometimes called ‘quick and dirty’ approaches.

The following lists some of the main tools used by production planners, namely: forward scheduling, backward scheduling, critical path methods, MRP, MRP11, OPT, line of balance, periodic and continuous methods of inventory planning and control, including the base stock system. The material requirements for a product are typically described by its bill of material (equivalent to the recipe for a cake) or, better, as a product structure, which for an engineering product shows what goes into what and was therefore called by Vazyoni ( ) a ‘gozinto’ chart. This may also be expressed as a matrix and is used in this way by Grubbstrom to represent MRP as an input output problem (ref).

Critical path analysis (CPA) or network analysis
CPA assumes that the times for each activity and the precedence relationships that define the sequence of manufacture (e.g. you do not put the nut on the bolt until you have put the bolt through the hole), are known. The analysis first does a forward path analysis and then a backward path analysis to find the float and the critical path i.e. the path on which any delay will delay the whole project. CPA is used regularly for project control e.g. of a construction project but it may be too detailed when there are multi products to process through a machine shop. Obtaining the necessary data may be time consuming.

Backward scheduling to infinite capacity
Backward scheduling is an approximate method of scheduling that works backwards from the desired completion time for a product. It generally assumes that it will take a standard time to buy or make the required components and products. Backward scheduling to infinite capacity ignores possible shortages of men or materials and sets targets for each key stage in production or even the times for each individual operation to be completed on machines. It does this by subtracting the assumed lead time from the selected completion date. The assumptions that there is infinite capacity, that machines will not break down, that material is of the appropriate quality, that material deliveries will be on time, etc. means that reality will not conform to the derived schedule. To overcome this there is a need for feedback to say what has happened. Then there will be a need for rescheduling to ensure that the next schedule to ensure that that the next schedule starts from a position that is consistent with reality. The use of standard lead times can mean that the schedule may ask for an activity to be started and even completed before now i.e. the current time. Although this is a logical contradiction, the calculated ‘lateness’ can be used to prioritise activities that are waiting.

Intermediate scheme data and comments
De Havilland had a functional organisation. We described the system that was being used before the intermediate scheme was implemented as ‘heap and hope’. In other words as soon as the company had information about an order it was released to the shop floor. In a sense the orders were heaped onto the shop floor and it was hoped that they would emerge on time. Manual progressing was used to deal with priorities e.g. when items were released late or were behind schedule for other reasons. This was achieved by de Havilland employing many time clerks to record the work that had been completed and

many progress chasers to expedite the work that was behind schedule. One symptom of this method of production control was that each month there would be overtime worked to finish that month's programme of work, the real objective against which performance was being judged.

The intermediate scheme assumed that it was reasonable to perform 2 operations on a component per week. This implied that each component had an individual standard production lead time that depended on the total number of operations. For convenience components would be known as 6 week (approx 12 operations), 8 week (16 operations), 10 week lead time components, etc. Using the required finish date, target dates would be calculated for the start and finish dates for each operation of each component. This meant that jobs would wait until the appropriate time before being issued and so as the scheme became operational there was less work waiting. It was assumed that there would be a queue of work waiting to be performed at each machine/machine group and the scheme operated using lateness as a priority. Late items went to the front of the queue and early items would go to the back of the queue. The punched cards for each operation became the job cards and when the work was processed these were recorded. Hence, at the end of every week it was known where each item was. The same process could then be repeated on a week by week basis. A reasonable amount of discretion was allowed if idle time was apparent.

Roughly the steps were:

1. Start with an individual component target completion time
2. Subtract the standard operation lead time (1/2 week) from the completion time to produce an operation start time, which became the completion time for the previous operation, and so on.
3. These operations were then sorted by time within machine group and so basically produce a week by week schedule for each machine group.
4. If the start time for any operation is before the present time then, the lateness decides the priorities in which the queue of operations should be tackled at each machine.
5. If there are major problems because of material shortages, quality problem, overloads, or other priority changes then there will probably be a need to reschedule.

All components were rescheduled on a weekly basis to take account of achievements. Figures A3.1 shows some results of the intermediate scheme.

Figure A3.1 about here

MRP

Material Requirements Planning (MRP) is probably the most commonly used basis for production planning and control. Broadly MRP has the following steps:

- Master scheduling
- Requirements planning
- Produce the purchasing and manufacturing requirements

- From these are derived the purchasing and manufacturing schedules.

Master scheduling is the process of producing the Master Production Schedule (MPS), which is an attempt to make planning more defined. The MPS says what products need to be produced on a period by period basis for some planning horizon into the future. The MPS is considered to be a firm and realistic commitment determined under the authority of a senior executive and signed off by senior management including Sales, confirming that they can sell these, Production confirming that they can make the products and Finance confirming that they can cover the financial commitments that the targets imply.

The requirements planning procedures use the MPS, the bill of materials, and lead time data for products manufacture, part manufacture and material delivery. The steps involved in materials requirements planning are to perform:

- Gross requirements planning. This uses the product requirements from the MPS to produce the gross parts requirements e.g. if the MPS asks for 2 tables to delivered and each table has 4 legs then the gross requirements for legs will be 8 legs
- Net requirements planning. The net requirements are calculated as the gross requirements less the stock. Hence, if there are 2 legs in stock, the net requireme4nts will be 6 legs
- lead time offset. This takes account of the time at which the derived net requirements are required and subtracts the lead times to determine when the parts should start manufacture and when the material should be ordered
- Batching. This adjusts the net requirements to order in economic batch sizes.

Thus MRP produces the quantities and times when materials should be ordered (and be available) and the quantity and times when parts are to be started (and finished). These are the basis of a purchase schedule and a manufacturing schedule. The resulting loading on men and machines may be derived from the above to form the machine and labour requirements.

MRP11

Basically MRP11 uses MRP i.e. MPS and backward scheduling but checks the consequential resource usage and smoothes the work load possibly by shifting overloads between periods.

OPT

OPT uses operational performance measures that are consistent with strategic decisions. Basically uses MRP for its first attempt at scheduling in order to identify bottleneck machines and then uses CPA for detailed scheduling to and from the bottlenecks

Assembly line sequencing and balancing

The assembly line balancing problem allocates work elements to work stations either to

- Minimise the size of the workforce required to achieve the desired output, or
- Maximise the output e.g. when the workforce is fixed and demand is increasing.

To achieve these objectives, assembly line balancing uses the precedence relationship that defines the manufacturing sequence, any other constraints that limit flexibility such as fixed location facilities (e.g. large machines, plating facility etc), and either the number of assemblies that are to be produced per unit time or the number people that will man the line. In some companies the allocation of workers to the line is only done when it is known how many people have arrived for the start of a days shift.

With mixed model assembly lines, different products (usually variants of the same basic product e.g. different engine size, different extras) are made using the same facilities. There is then a need also to determine the sequence in which assemblies are to be made on a product by product basis, probably for the shift that is being worked. (This is logically the same problem as the flow shop sequencing problem mentioned in the main text.) Operationally, the supply of the appropriate parts obviously has to be co-ordinated with this the chosen sequence

Inventory control methods
In general, inventory control systems decide when and how much (or how many items of) stock to order. The two many approaches that are used are:

- ‘Continuous review’ methods. These review stock levels that after every transaction
- ‘Periodic review’ methods. These review stock levels periodically e.g. weekly.

The base stock system
If it is known that it takes 3 weeks to produce something then a pipeline stock of three weeks should enables items to be produced on a progressive basis. If the production level is pretty constant say at 100/week then the base stock would be 300 items together with any safety stock adjustments to protect against variation in demand, scrap, etc. That could require adding an extra 100 items (say).to the base stock. If the weekly requirements were known to be 100, 130, 140 say then the base stock would be 370 plus safety stock, which if was still 100 would produce a base stock of 470. Renold added control of the first operation and of the last operation and the shop floor could use their discretion to control the flow between intermediate operations. This produced a good smooth flow.

The material and information flows associated with the various production and inventory planning and control systems are summarised in Figure A3.2.

Figure A3.2 about here

This document is incomplete