MODELLING

A **Model** is a representation of some aspect of the real world: in systems engineering it is a representation of system to explore some aspect of interest.

Because models do not need to represent all the real system's complexities they can be used right from the start of the project. It could be argued that almost all of the analytical and decision making work in systems engineering is based on models. Even if that is a slight exaggeration, modelling is crucial to the systems engineering process.

A point made in Blanchard and Fabrycky is that System modelling in Science when it is an attempt to understand nature as it is, is different from the objective in Engineering where models attempt to explore what things ought to be.

Abstraction

The key feature in the production of a model is to simplify reality in a way that maintains the same characteristics of the real system in the aspects that are of interest while ignoring those things that are not of interest. This process is known as **"abstraction".**

WE HAVE ALREADY SEEN

Modelling covers a very wide range of things and we have already been using them throughout this course, e.g.

Lenny and Terry (physical models)
Diagrams and networks (schematic models)
Mass and Relaibailty models (mathematical models)

Even the very concept of a system is a model.

We are now going to look at some of them specifically and in more detail.

Dynamic Models (today)
Parametric Models
System Models
Stochastic Models

TYPES OF MODEL

Physical Models: Geometric equivalents of the system - i.e. what classically is called a model.

Analogue Models: Models that are not geometric equivalents but have similar relationships from Greek analogia meaning proportional and hence word analogous. At one time it was common practice to model system behaviour with electric (rather than electronic) circuits on analog computers (these days digital computing does it mathematically).

Schematic Models: Diagrams that represent the system. Indeed our concept of a system is a schematic model of the complex reality.

Mathematical Models: Where the system is represented by mathematical relationships. A very wide ranging definition including simple equations to the most complex computer simulations.

At a more fundamental level our language is a modelling process where reality it abstracted into words that can be placed in different patterns to create models of how we perceive reality. As all our conscious thinking is though language.

Indeed as all thought is some form of modelling - our experience of life is through models.

WHAT IS MODELLING USED FOR?

Design Analysis
To produce data to guide the design process, find optimum design solutions, and understand the impact of design decisions.

Qualification
To verify the design for qualification purposes. Note: it is not really possible to use modelling as an acceptance test.

Marketing
Modelling to show potential customers what the system will do. This is having increasing impact as computer graphics improve.

Training
Simulations of the system to enable training of operating personnel. Physical models have always been used for this purpose, now there is increasing use of software models.

Understanding the function a model is to perform enables the right level of abstraction to be determined. Over-abstraction can give misleading results, Under-abstraction means too much work and a danger of missing the big picture in the detail.

TYPES OF MATHEMATICAL MODELS

Empirical Modelling - (most commonly Parametric modelling) using mathematical relationships based on empirical data. That is looking at past experience and plotting relationships between a parameter that can be established and a parameter that is of interest.

Analytical Models - (the opposite of Empirical Models) these are models where the mathematical relationships are derived from logical consideration of the system.

These can be either:

> **Deterministic Models** - where the output of the model is solely dependent on the input. Thus every time it is run it will produce the same result.
>
> **Stochastic Models -** (the opposite of Deterministic Models). The model contains some probability function and the output is not solely dependent upon the input but also on some random component with in it. Thus it will not produce the same result every time it is run.

And either:

> **Static Models -** Models with have no time dependant component. Normally open loop models of some form which act on one system state to produce another.
>
> **Dynamic Models** (the opposite of Static Models) - Models which have a feedback component were the output system state is the input for the next step. Used to determine the time dependant behaviour of a system.

EXAMPLES

Some examples of models used in aerospace systems engineering.

Finite Element Structure Modelling - Computer modelling of structure strength and stiffness.
- Dynamic modelling to get frequencies and Static modelling to get strength and distortions, Deterministic, analytical.

CFD Models - Finite element modelling of air flow around the system
Analytical, Deterministic, Dynamic.

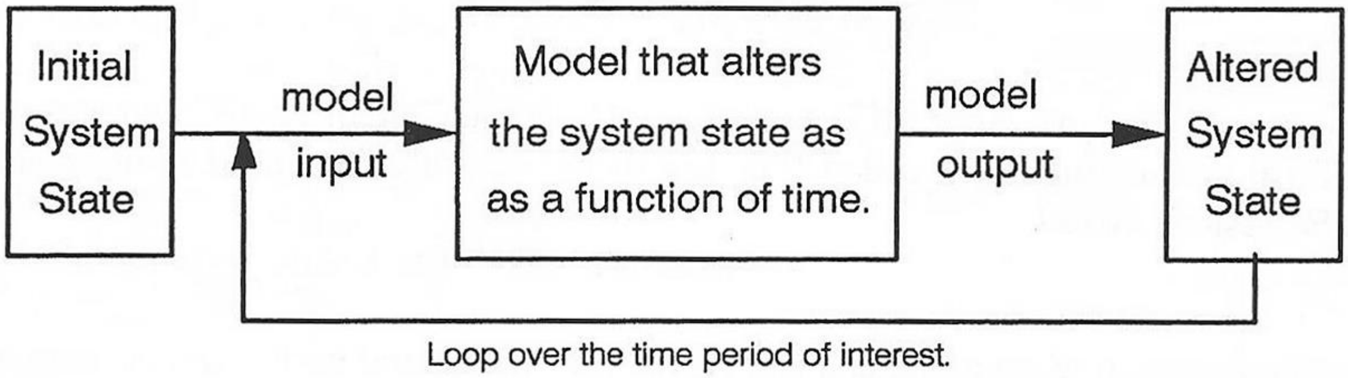
Cost Modelling - Using estimated masses to get the development and production costs
parametric, deterministic, static.

Passenger Traffic Modelling - Various ways of modelling predicted traffic.
Normally static, stochastic

Control System Model - Model of the control system to check for response, stability etc.
- If automatic control generally deterministic, If a humans is in the loop then model is normally Stochastic, Analytical, Dynamic

DYNAMIC SYSTEM MODELLING

This is when the model explores the system behaviour over time. The key feature of a dynamic model is that the output state of the model after one step is used as the input state for the next step.



The main application of dynamic modelling is in examining the behaviour of closed loop feedback control systems.

GLOBAL DYNAMIC MODELLING
A Case Study

Forrester of MIT was one of the early pioneers of computer based dynamic modelling of systems but caught megalomania and started modelling things like factory industrial relations, cities and finally the whole global economy. The studies came to generally very negative results about the potential of human industrial civilisation.

Jay W. Forrester - "World Dynamics", Wright Allen Press 1971

This work was extended in a large MIT study funded by "The Club of Rome" and was published in popular form in a seminal book called "The Limits to Growth". They used an upgraded version of Forrester's model.

Meadows et.al.- "The Limits To Growth", Pan 1972

It caused a big sensation when published and is still very influential in the environmental movement - especially among Neo-Malthusians who believe that industrial civilisation must eventually give way to a post-industrial society.

Because they are large, well publicised, and every little problem with them is well chewed over they make a good case study for mathematical modelling techniques and some of the issues with them.

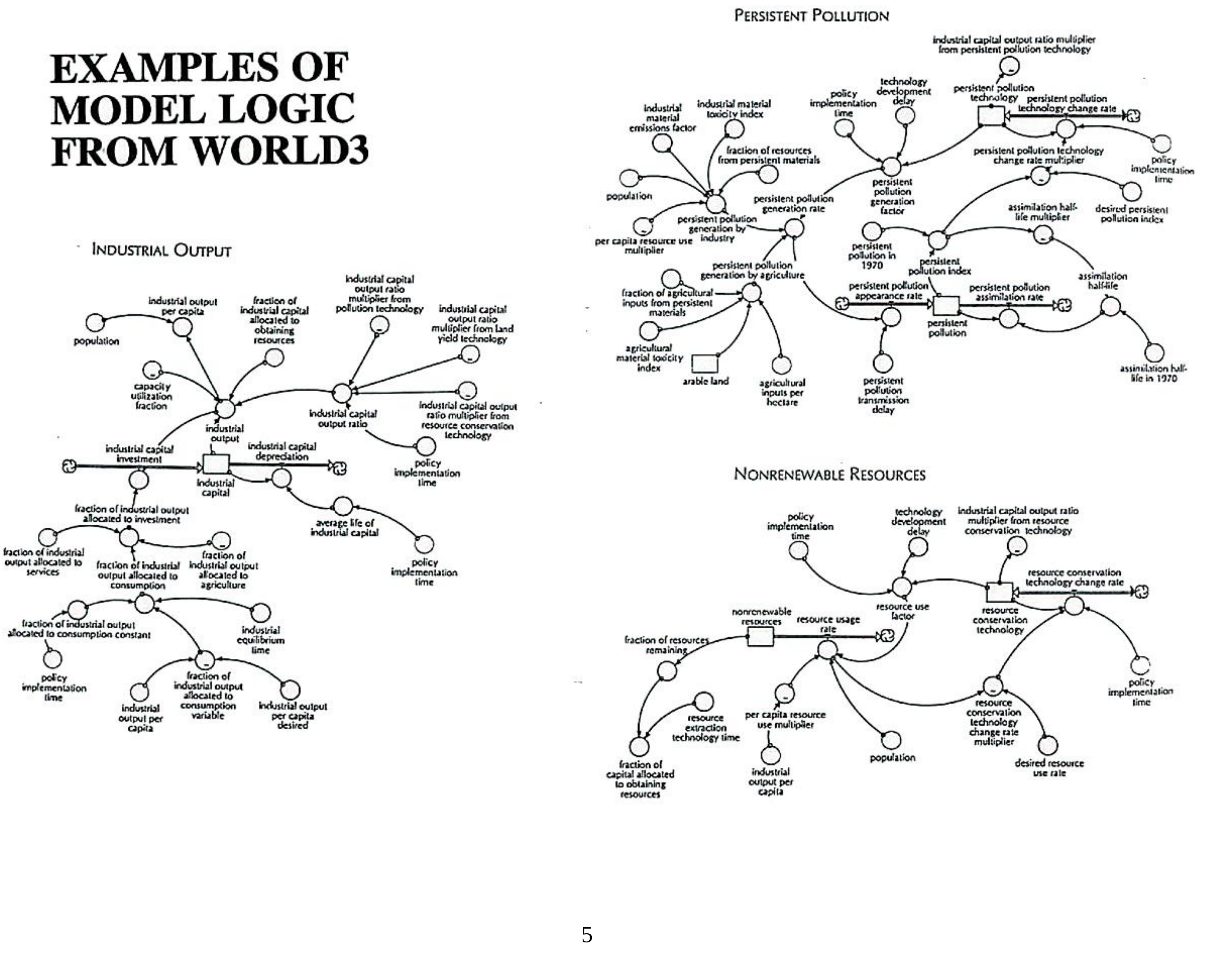
THE MODELS

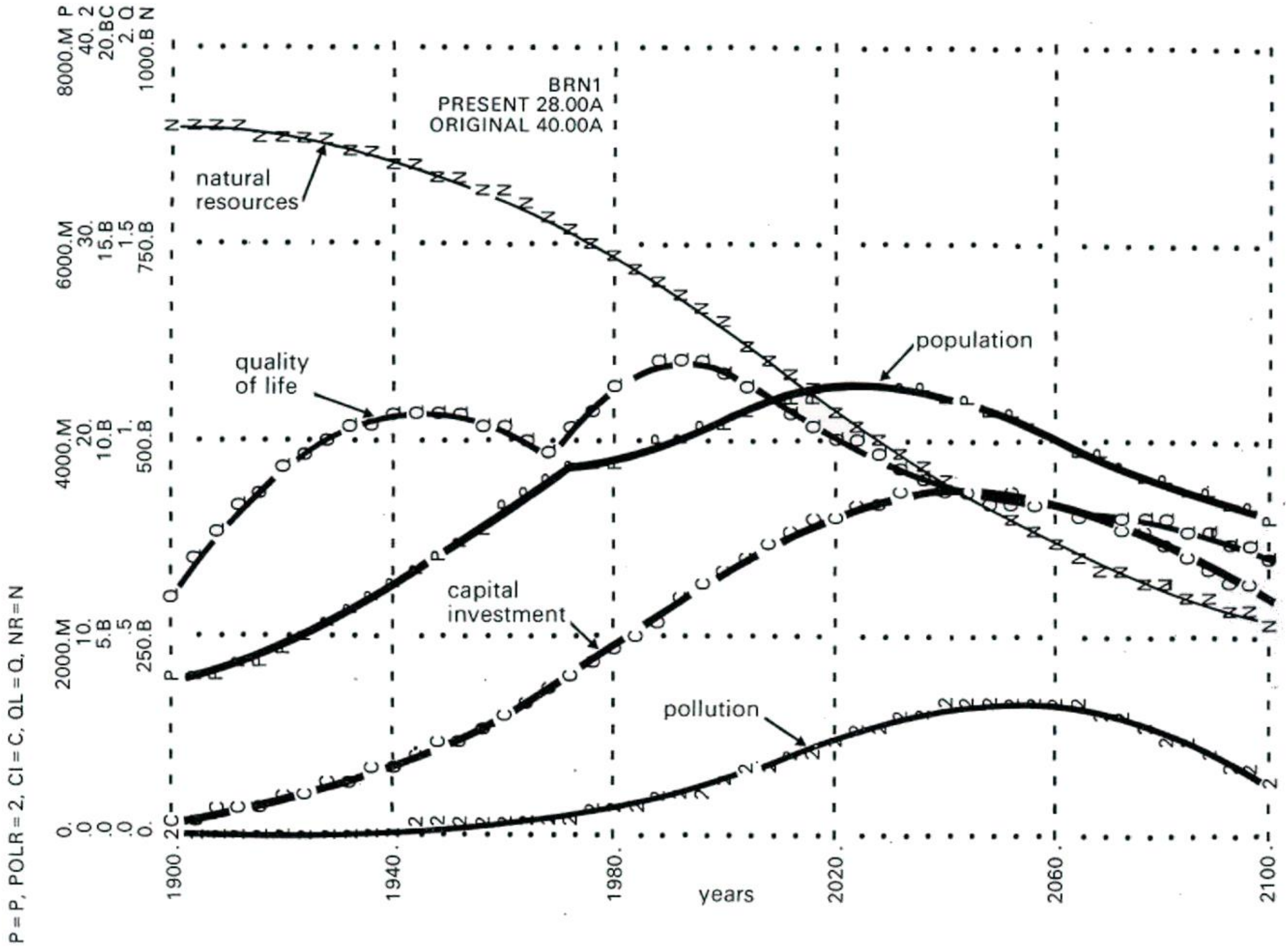
Forrester's model (called World2) used 115 equations to define the relationship between various parameters of interest in the world economy. The "Club of Rome" modellers used a larger model called World3.

As the name suggests the models are **Dynamic** that is they use feedback loops to perform step by step calculation the output system state being the input for the next step. This enables the behaviour over time to be studied.

The data and mathematical relationships in both the models are obtained from a combination of empirical and analytical methods. It is the establishing of these relations that makes Global system modelling such an expensive exercise needing large grants to do it well.

Originally (over the 1970s) these models were run on large "mainframes". This gave them even more credence to the results ("it comes from a computer so it must be right") and only people with access to large computers (and the budgets to buy the run time) could check the results. These days the models can be run on desktop computers and anybody can play.





PROBLEMS - OVER-ABSTRACTION

Despite their complexity it is clear the Global Dynamic Models are a gross simplification of the real world. That would be OK if the behaviour it exhibited still corresponded to the real world - that is the results are valid for the use they are intended.

The first abstraction problem is that only population is directly measurable. The others a vague generalisations with composed of many related factors.

The main criticism of the models that caused even the MIT team to rethink (Meadows et al "Beyond the Limits" - Earthscan) was that the original model did not include any effect for technology advance. In other words it was made too simple.

Subsequent researchers found if factors were introduced that assumed materials technology would find substitutes for resources and that pollution would also be more controllable with new technology many of the pessimistic prediction the model could be reversed.

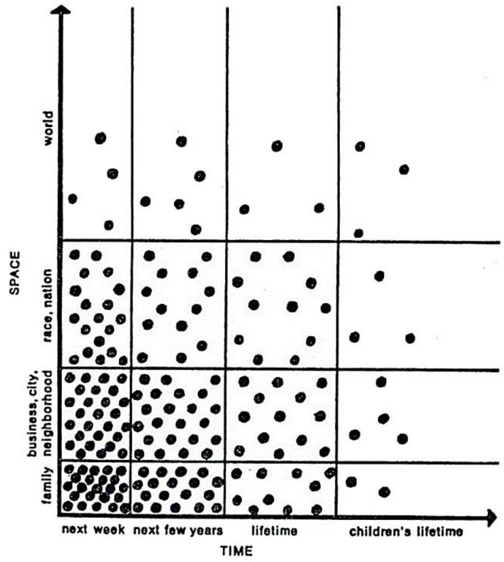
However the actual mathematical relationship between technology advance with time and the impact on resources and pollution has not proved possible to define (either empirically or analytically) and in the end whether you believe this will change the pessimistic conclusions or not depends upon personal judgement. So the original model results as presented by Forrester and Meadows cannot be treated as irrefutable but again neither can they be dismissed.

PROBLEMS - THE SYSTEM BOUNDARY

This is the main problem identified by Space enthusiasts (Vajk, Martin, Shultz, IASA in Japan). This diagram is taken from "The Limits to Growth" and tries to show how open minded and far seeing the authors are. In fact it shows they treat human activity as being confined to the Earth. So they model the global system as having no system interfaces.
(i.e. none cross the system boundary - if you have forgotten).

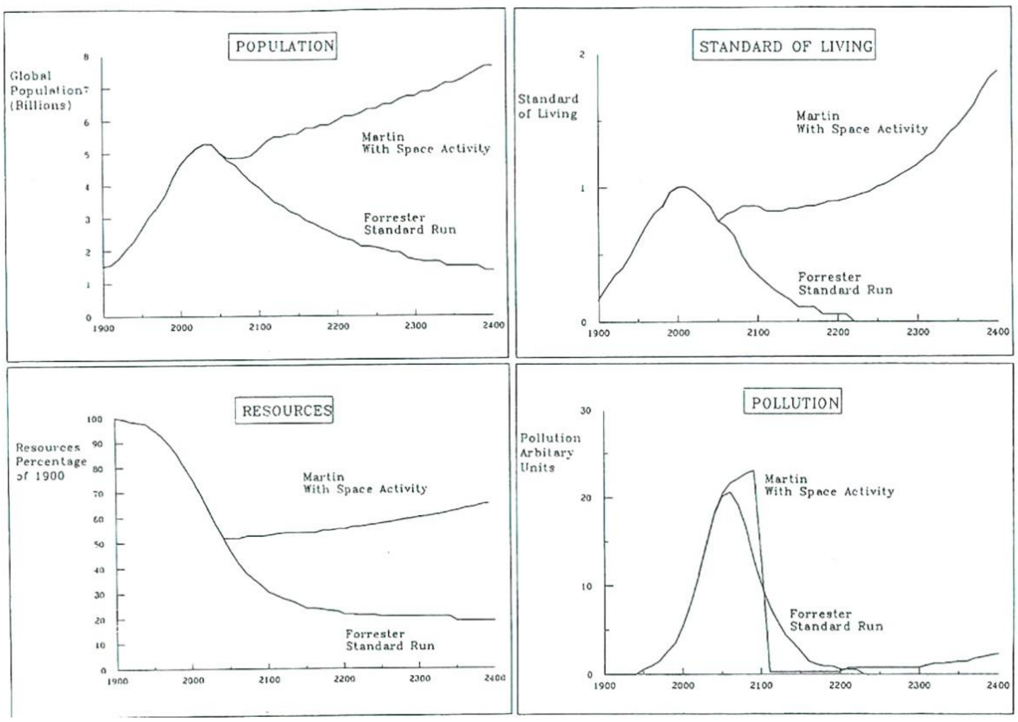
If space industrialisation is added into the model such that energy can be cleanly generated by space based systems and resources can be increased by extraterrestrial mining. Then the impact on the models is to show continued indefinite growth.

Figure 1 HUMAN PERSPECTIVES



Although the perspectives of the world's people vary in space and in time, every human concern falls somewhere on the space-time graph. The majority of the world's people are concerned with matters that affect only family or friends over a short period of time. Others look farther ahead in time or over a larger area—a city or a nation. Only a very few people have a global perspective that extends far into the future.

The issue centres on whether space industrialisation can be achieved in sufficient quantity and in time.



PROBLEMS - PERSONAL AGENDAS

Here we must return to one of the early lectures and the warnings about what constitutes a system. The Global economy is not an engineered system - it is a natural system that has evolved. It therefore has no requirement specification and more important no definable objective.

When the Space industrialisation lobby presented Dennis Meadows with the idea of large space colonies to resolve growth issues his response was

I am not sure that we should want to have another frontier. It seems to me to block constructive response to the problems here on Earth. If you look around at societies to find those that have come into some sort of a peaceful harmonious accommodation with themselves, many of them turn out to be on islands, where the myth of a new frontier vanished long ago. [13]

In other words he does not see the demise of industrial materialistic civilisation as a bad thing - he believes the limits to growth will force mankind into what he considers to be a better way of life.

Of course the space enthusiasts who use models to show how they lead to continued economic growth are also biased in favour of that solution. They argue that the models show you must go into space to maintain growth, but they also see a future of materially rich people with access to the entire Solar System as a desirable future for mankind.

So even if there is agreement the models are producing realistic results that should be taken seriously there is still a strong element of personal judgement about what a "good" outcome is. Fortunately in engineering these problems are normally resolved by the definition of purpose objectives and requirements.

PROBLEMS - RANDOM BEHAVIOUR

The Global dynamic model are **Deterministic** that is they always give the same answer for the same input. The implication is that for a given state of the global economy it will always move broadly in the same direction.

The modellers do explore options in policy but the underlying assumption remains that a given policy will inevitably lead to a set result remains.

In real life the global economy and human affairs is influenced by random – i.e unpredictable - events. The question that hangs over the modelling is do these random elements affect the broad conclusions of the modelling or not.

A debatable point - things like population growth do seem "deterministic" - the Second World War is the only "event" detectable in the historical population growth curve and one has to look hard for that. The effect of climate changes, technology impacts, and such factors are random and may change the model's behaviour.

To address the issue of random factors in a system non-deterministic(**Stochastic)** modelling is required. And so far as I know this has never been attempted.

SUMMARY OF ISSUES EFFECTING ALL MODELS

All of the following could prove an issue affecting the validity of a model for its stated objective.

1 - Level of Abstraction
Is the model too simple or too complicated for its intended use?

2 - The System Boundary
Is it accurately modelled together with system interfaces?

3 - Personal Agendas
Has the personal objectives of the modeller influenced the modelling itself?

4 - Random Behaviour
If a deterministic model is it safe to ignore the uncertainties in the real world