Dynamic Modelling

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This Presentation

I will argue that System Dynamics provides the right tool to model dynamic processes and change. To do this I will demonstrate three things:

- It provides the right language for modelling processes through time
- It is practical, with good software and a substantial body of experience
- It works
  - The Dynamic Urban Model
  - Research for DfT

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**The Right Language**

System Dynamics is:

- A computer simulation technique
- Concerned with system structure and behaviour
  - Cause and effect relationships
  - Feedback
- Used widely to model complex systems:
  - Business/industrial
  - Social
  - Economic
  - Environmental
  - etc

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The Right Language: Stocks and Flows

- There are two fundamental variable types
  - Stocks
  - Flows
- A stock is an accumulation of something:
  - People
  - Buildings
  - Brownfield land
  - Cash
  - Water in the bath
- Usually physical quantities, but they don't have to be:
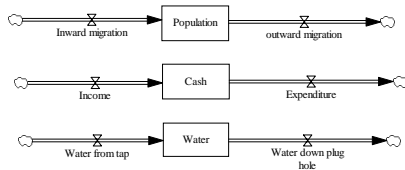 - Expected share price
  - Experienced travel conditions

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Stocks

- Stocks are represented diagrammatically as rectangles

Population

Cash

Water

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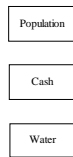
Flows

- Flows add to or take away from stocks
- They are 'rates of change', and are represented as 'pipes' with 'valves'

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Stocks and Flows

- We may have several flows

Births | Deaths
Population
Inward migration | outward migration

- And material may flow from one stock to another
  - But cannot change its physical units

New recruits → Trainee staff → Completing training → Qualified staff → Resignations

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Stocks and Flows

- Mathematically, flows are rates:
  - Flow of people: d(people)/dt
- While stocks are accumulators, or integrators:

$$Stock(t) = \int_{t_0}^{t} \left[Inflow(s) - Outflow(s) \right] ds + Stock(t_0)$$

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Right Language: Information and Decisions

- SD has always been concerned with how people use information to make decisions
- Social system behaviour is largely driven by the way this works
- The information people use may be:
  - Partial, maybe because some information is not available, or because people choose not to use it
  - Out of date - it takes time to assemble information and for it to be dispersed
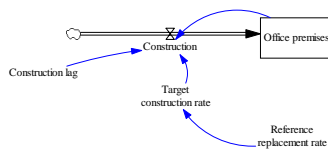 - Wrong

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Developers and construction of premises
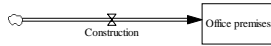
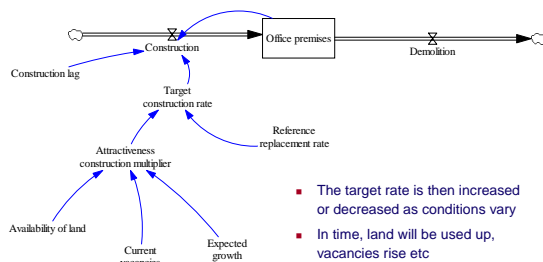Developers build new premises

- Include here new build and refurbishment

Developers and construction of premises

- We can prime the model with a target construction rate – the replacement rate.
- Developers are concerned with:
  - Availability of land
  - Current market conditions (ie rents)
  - Future prospects

Developers and construction of premises

- The target rate is then increased or decreased as conditions vary
- In time, land will be used up, vacancies rise etc
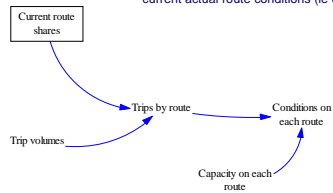- Add demolition ..

Developers and construction of premises

- Availability of land
  - In real world it's price
  - We use fraction of land area available
- Current vacancies
  - In real world, price again – rents etc
  - We use fractional vacancy rate
- Expected growth
  - In real world, forecasts, projections, judgment
  - We use moving average growth rates as proxy for forecasts

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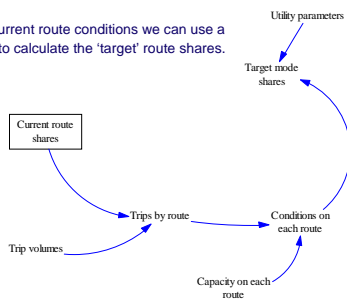
Information and Decisions: Route Choice

Current (ie modelled) route shares plus current trip matrix are used to generate movements on each available route.

By comparison with the capacities, this gives the current actual route conditions (ie congested times)

Current route shares

Trips by route

Conditions on each route

Trip volumes

Capacity on each route

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Information and Decisions: Route Choice

Given the current route conditions we can use a logit model to calculate the 'target' route shares.

Utility parameters

Target mode shares

Current route shares

Trips by route

Conditions on each route

Trip volumes

Capacity on each route

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Information and Decisions: Route Choice

In time, people learn and adapt to the new conditions, changing the route choices. This will then alter conditions …
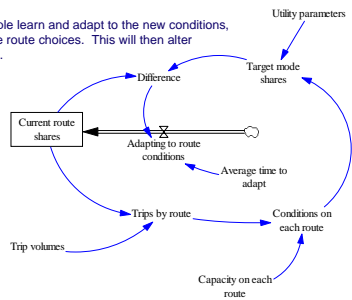
Practical Tool: Software

- Lots of good graphical software developed in 1990s
- We use Vensim
  - graphical interface to build models,
  - a huge range of model testing and error trapping tools,
  - Tables and graphical outputs
  - Interfaces with other software (eg Excel)

Practical Tool: Theory & Practice

- Substantial body of theory and experience
  - Industrial Dynamics (1961)
  - Business Dynamics (Sterman, 2000)
  - SD Society bibliography lists over 12,000 references

It Works: The Dynamic Urban Model

It was built primarily to help answer questions about the links between transport and economic activity.

It's a simulation of how an urban area evolves over time, focusing especially on the interactions between:

- Transport
- Businesses & the local economy
- Population
- Land use

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The attractiveness of a location

- Each neighbourhood (zone) in a town or city may be more or less attractive for different types of activity
- Where attractiveness is high, then more activity will tend to occur – until new constraints are hit, or attractiveness starts to drop again
  - Eg rising congestion, shortage of land
- The model looks at attractiveness from four points of view:
  - Businesses and employers - as a place to do business in
  - Households - as a place to live
  - Commercial developers - as a place to build new business premises
  - House builders – as a place to build housing

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Businesses

Businesses need:
- Suitable premises
  - Vacancy rates, by type
- Access to a suitable workforce
  - Fraction of jobs unfilled
- Access to customers and suppliers
  - Businesses within range

If these are in supply, attraction rises; if not it falls
- Ultimately these can be limiting factors to growth

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Attractiveness as a place to live

There are many factors, of course. This model focuses on two:

- Availability of suitable housing
  - Fractional vacancies
- Access to suitable employment
  - Average time to find a job

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Attractiveness for developers

Developers look for:
- Land
  - Fraction of area
- The expectation of growth in demand
  - Moving average rate
- Under-supply – or at least, not over-supply
  - Vacancy rates

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Attractiveness for house builders

- Land
  - Fraction available
- The expectation of growth in demand
  - Moving average
- Under-supply – or at least, not over-supply – of units
  - Vacancy rates

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The Role of Transport

Technically, the model can represent transport networks in usual way:

- Link based, private, public etc; or
- Generalised costs

The *role* of transport is to provide:

- Businesses with:
  - Access to a workforce
  - Access to customers
  - Access to suppliers
- Households with:
  - Access to employment
  - Access to services

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What it looks like: the recruitment cycle

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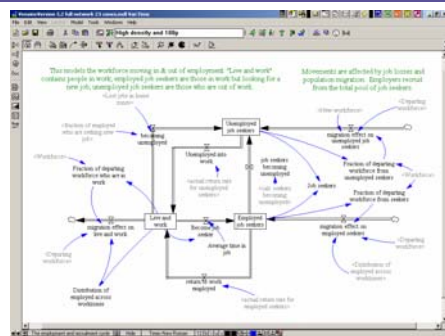
## The Impact of Transport on Business Locations

Customised version of the model

- Businesses
  - Startups, expansion, closures etc
- Developers
  - Building new business infrastructure
- Transport
  - Link based networks

- Household numbers supplied externally

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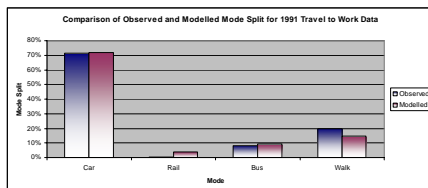
Business Locations: Case Studies

- We set up two case studies
  - Milton Keynes
  - S&W Yorkshire
- Simulate developments 1991 – 2001
  - Assemble baseline using census, ONS data etc describing what actually happened
  - Transport changes edited retrospectively into networks
  - Model set up to represent 1991 then simulates next 10 years
  - Test is numbers of jobs and businesses per zone, modelled & actual

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Milton Keynes Case Study
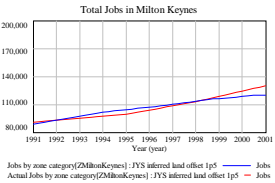

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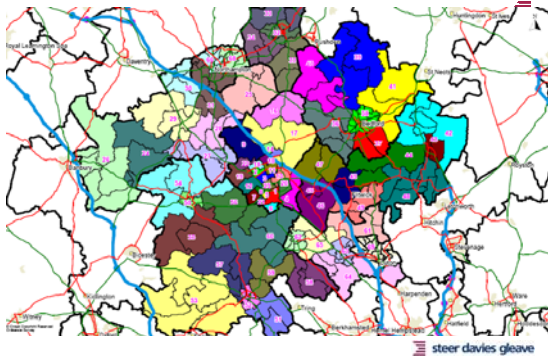
Setting up the MK case study

- The model is initialised with generalised costs, workforce, businesses etc for 1991
- We check that it generates acceptable mode shares and ttw matrices for that year, with static numbers of businesses and workforce
- It is then run for ten simulated years, with the initialised ttw matrix, all dynamics turned on, reading in intermediate values for Generalised costs and workforce
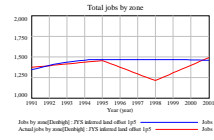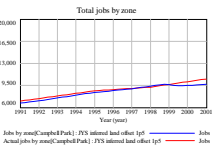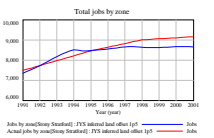

Comparison of Observed and Modelled Mode Split for 1991 Travel to Work Data

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The importance of Time in Transport Modelling

- Because conditions now are a result of decisions made in the past, and many of these decisions are persistent for a long time:
  - New buildings – planning time, then lifetime of decades, at least
  - Businesses – choice of location a significant commitment – reluctance to change
  - Household locations - similar
- Because people take time to learn and adapt
  - Information may be dated

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The importance of time in Transport

A change in transport can lead to changes in travel patterns via several cause-effect links, operating over very different timescales.

Eg for travel to work:

- Mode shift for existing trips
- Pool of accessible jobs changes so travel-to-work patterns alter via recruitment
- Ease of recruitment changes attracting/deterring new employers
- Employment conditions change so household migration changes

Days, weeks

Months, years

Years, decades

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In conclusion

- We need to understand dynamics though time
- System Dynamics offers a modelling framework to do this
- There is a substantial body of theory and experience
- Good software exists
- It is being used in real transport applications

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