EXECUTIVE BRIEFING SERIES

SYSTEM DYNAMICS & SIMULATION MODELLING

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THREE MEDIA ASSOCIATES LTD

TMA works with broadcast and media companies to plan and implement major business and technology change

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1 EXECUTIVE SUMMARY

Do you recognise the following problems and have they been hard to diagnose or fix?

- Why when we added more people didn't the job get done quicker?
- How come the computer takes so long to do that job, we added extra memory and storage and it made no difference?
- The IT guys said we'd be able to cope with that large new client, but now everyone's service levels are dropping – that's bad and costly…
- Why does it look like people are sitting around doing nothing – what are they waiting for?
- We removed that item of kit as capital was tight. Let's hope it isn't needed when we migrate over to using the new supplier for our increased translation needs.

A necessary part of everyday business infrastructure is an IT system that may in itself rely on other external businesses or systems. The IT service is often viewed as a business asset, similar to a vehicle or real estate, where it is managed financially, operationally and strategically. Financial measures include the capital cost of acquiring, owning and disposing of it, operational topics include its maintenance costs and rules of how to control it, and strategic decisions include what it should be, where it should reside, and who should own, manage and use it. Sadly this approach has very limited accuracy in forecasting expected outcomes, or managing problems in service levels when they arise.

One of the main reasons for this poor accuracy is that an IT system is not like a vehicle or real estate, but is more similar to people where its capacity, behaviour and interactions will vary over time, be effected by other parts of the business environment, and have periods of absence, aberration and fluctuation. Therefore there are serious questions as to the validity and accuracy of a simple model such as a spreadsheet to plan or manage IT metrics.

This paper explores an alternative approach based upon system dynamics (SD). SD models the micro characteristics of a business or IT system and runs a simulation over time to show how each part of the system behaves and thereby answer macro questions of throughput, capacity, cost and service level characteristics.

Business Process Re-engineering (BPR) is a way of analysing a business with the intention of changing the business processes, rules or business strategy, to improve the service levels or competitive advantage. SD can be a key component of the selection of the BPR preferred initiative, or be involved in the whole BPR activity to guide and validate the decisions you make.

Businesses that can benefit from the SD approach are those where the technology, or business infrastructure, is too complex to understand or model by more traditional techniques such as spreadsheets, financial estimating and budgeting, or parametric models. It has been used with great success in the broadcast industry where there are large amounts of complex and inter-related data that is stored globally and needs to be accessed and processed in real time.

The concepts of SD modelling, and the diagrams that define them, are explained in this paper.

2 WHAT IS SYSTEM DYNAMICS?

System Dynamics is a way of looking at every day business problems and modelling them with a network of inter-related components that can then be run in a simulation of a period of time. The most common focus to use with SD is at the business level looking at the interplay between a business and its customers and other aspects of its business environment. However SD can also be applied to more detailed and specific questions such as the necessary capacity and topography of a network, the size and location of computer storage, or the business and operation rules that should be used to maximise profit or return on investment.

2.1 HISTORY

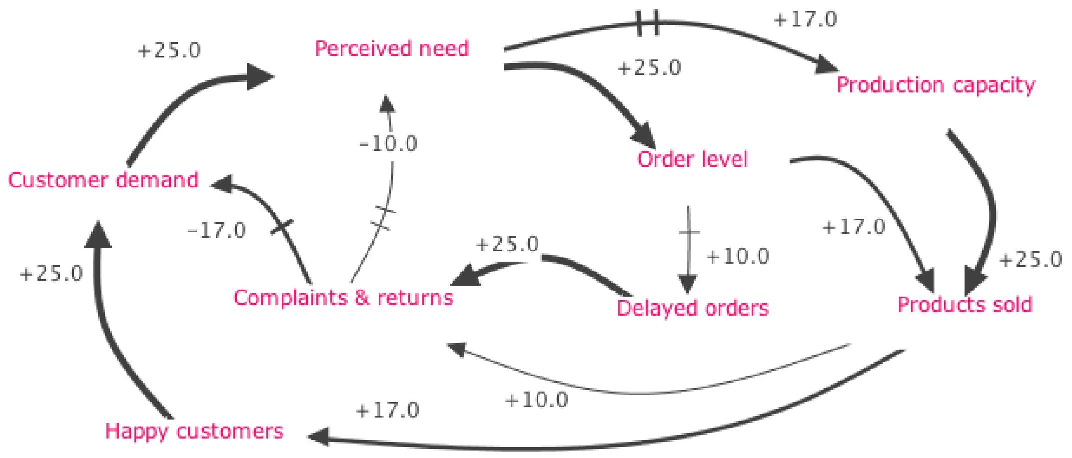
Professor Jay Forrester of the Massachusetts Institute of Technology created system dynamics during the mid-1950s. He used science and engineering techniques to understand why businesses succeed or fail and used his involvement with General Electric to formulate the Stock-Flow-Feedback concept that underlies the SD models. As computing evolved over the next couple of decades, so SD moved from being a hand drawn technique to being run by software. The use of SD to address political questions such as the arms race, world famine and the imbalance of population and wealth have helped to mature SD into a robust and flexible modelling technique.

2.2 WHY IS SD DIFFERENT TO BUSINESS/SYSTEMS ANALYSIS?

A fundamental building block of SD is that it is not enough just to model cause and effect – you must also track the effect onwards and identify the feedback loops within your system. Those feedback loops will also be likely to contain delays and alterations so that the results you actually get from a business action may be substantially later, and of a different type, than what simple cause and effect may indicate. This high level model of your business is therefore modelled using *Causal Loops*. It is important to understand these before attempting to build the SD equations, as very often the consequences that propagate around the loops are non-linear.

2.3 WHAT DOES A CAUSAL LOOP DIAGRAM LOOK LIKE?

With any business system one can take a high level view that looks at the key components that interact in causal loops. The diagram is often drawn free form on a whiteboard, with narrative text for the components, and arrows to indicate whether an effect will cause the next component to move in the same (+), or the opposite (-), direction, and can have a single or double line across the arrow stem to indicate a short or lone delay between the cause and the effect.



Causal Loop diagram for a manufacturing business

2.3.1 Understanding Causal Loops.

A Reinforcing Loop is where each component adds to the effect. The consequence of that loop is for the system either to grow exponentially, or to drain away to zero. In the diagram above the outer loop is reinforcing as each step in the loop increases the size of the next item round the loop thereby building an ever-increasing volume.

A Balancing Loop is where one or more effects are in the opposite direction and thereby balancing out the effect. The consequence of the balancing effect is for the loop to oscillate around a mean value. In the diagram above the Delayed orders create Complaints and returns that in turn reduce Customer demand.

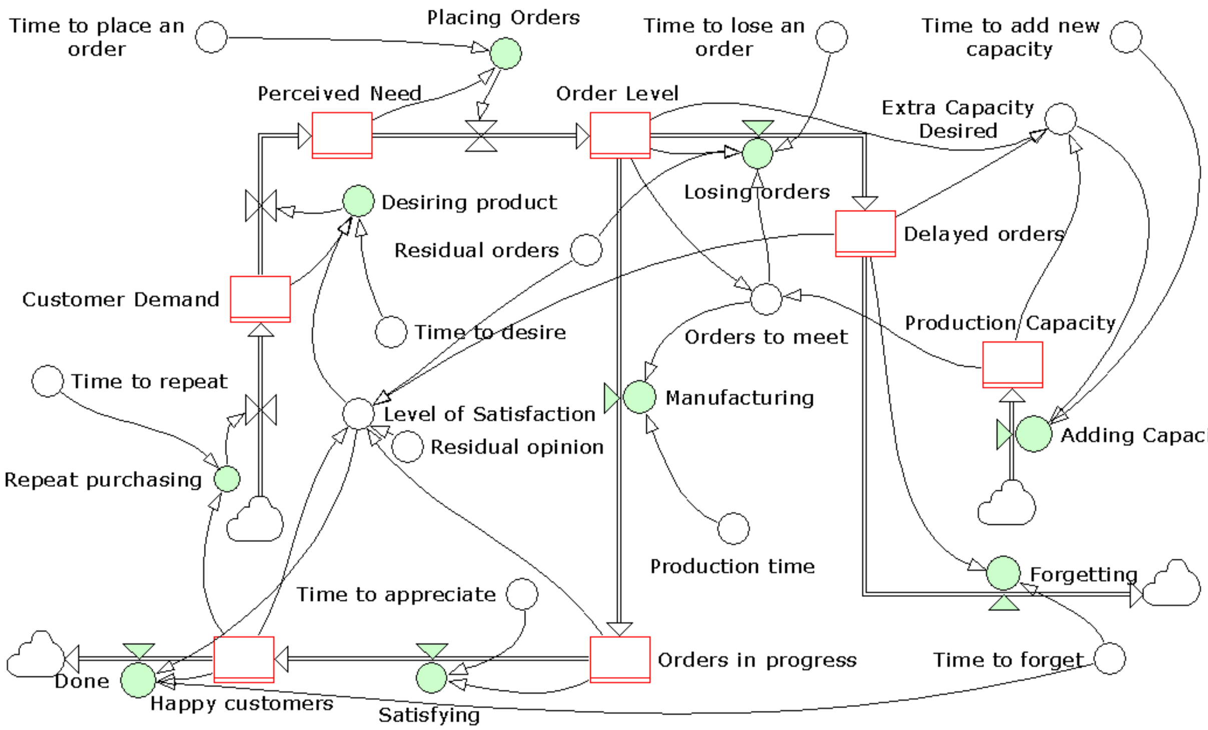
Closer analysis of the interplay of the forces in the diagram will indicate that the reason that products sold does not grow infinitely is that the quantity of delayed orders will increase as the Order level exceeds Production capacity. If the delay in increasing production capacity to meet demand is too long then the Customer demand could be driven to zero.

To draw causal loops you need first to understand archetypes. They are commonly occurring patterns in the real world that are represented in your model structure and behaviour. Archetypes include: Delay, Draining, Escalation, Eroding Goals and Limits to growth. In the diagram above the limit on Production capacity would be a limit on the growth of customers.

A robust SD model should model the gaps, delays, errors and latency inherent in your business situation. For example I may order a curry with chutney in a restaurant and the waiter only brings the curry. If he did not hear my order correctly that is then a gap, if he is going back to get it then that is a delay, and if I misunderstood and thought the chutney was separate rather than already mixed in then that is an error in my perception compared to the reality, and if he is getting it, but only after the chef tells him, then that is a latent delay as my goal for him has then in effect changed as far as he is concerned. In the diagram above there is a significant delay shown between when Perceived need increases and the consequential increase in Production Capacity – probably due to the time taken to make the financing decisions.

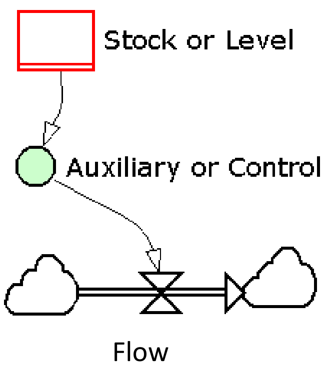
2.4 COMPONENTS IN A SYSTEM DYNAMICS MODEL

A SD schematic model looks very similar to a flow chart in that there are boxes connected by arrows down which something flows. A key difference is that there is not a start or finish as the model runs repeatedly around a cycle over a selected period of time. Therefore the model must contain some inflow from the outside to 'feed' the model, and some loops within the model to represent feedback and iteration or repetition. The simple model shown below is for the Causal Loops described earlier.



A System Dynamics Model - Schematic

The components of a SD model are as follows:



Stock or Level – Any asset that has limits and a starting value.

Link – a single arrow that connects one convertor, stock or flow to another. It is used to pass information.

Convertors or Auxiliary – Can be used to record the time taken to do things and the results of logical decisions and calculations.

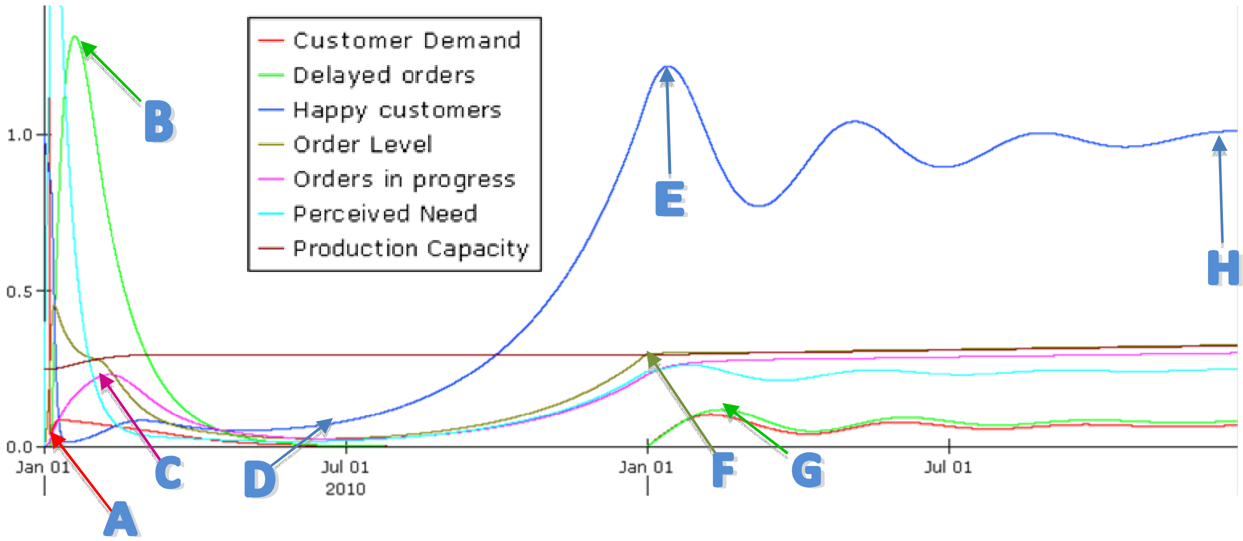
Flow – Shown as a double line with an arrowhead to show the direction of flow between stocks/levels.

Inside each symbol on the schematic diagram there needs to be a definition of either its starting value (if it is a stock) or the formula or logic that sets its value during the simulation. For example some of the formulae for the diagram above are:

Adding Capacity	'Extra Capacity Desired'/'Time to add new capacity'
Auxiliary or Control	'Stock or Level'
Customer Demand	3
Desiring product.out	'Desiring product'
Repeat purchasing.in	'Repeat purchasing'
Delayed orders	0
Forgetting.out	Forgetting
Losing orders.in	'Losing orders'
Desiring product	'Level of Satisfaction'*'Customer Demand'/'Time to desire'
Done	'Happy customers'/('Time to forget'*'Level of Satisfaction')
Extra Capacity Desired	IF (('Order Level'+'Delayed orders') > 'Production Capacity', ('Order Level'+'Delayed orders'-'Production Capacity'),('Production Capacity'-'Production Capacity'))
Forgetting	'Delayed orders'/'Time to forget'
Happy customers	1
Done.out	Done
Satisfying.in	Satisfying
Level of Satisfaction	IF ('Delayed orders' <= 'Residual orders', 'Happy customers'/'Residual opinion', 'Orders in progress'/(2*'Delayed orders'))
Losing orders	IF('Order Level'>'Orders to meet', ('Order Level'-'Orders to meet'), 'Residual orders')/'Time to lose an order'

Formulae for the components in a SD simulation model

If the business simulation is run over a period of time the stock levels vary as shown below.



Time chart for the Stock levels in the SD model

Customer demand at the start far exceeds production capacity and therefore falls nearly to zero (A). This is mainly due to the high number of delayed orders (B) that themselves drop as orders drop. However there are some orders placed and manufactured (C), and although the order level also drops to nearly zero, it recovers because happy customers (D) start to make repeat orders (as the product itself is good quality) and this reinforcement of repeat orders causes growth until (E) where the order level reaches the production capacity (F) after which there are again delayed orders (G) so that the repeat/delay orders oscillate until a balance is reached (H). This pattern of interplay then oscillation that settles down to trend, is common in SD systems.

3 HOW TO CREATE A SIMULATION MODEL?

The steps in creating a simulation model are:

1. In plain English define what problem, or question, is to be solved. E.g. "*Does our web server have enough capacity to support our expansion into North Africa?*"
2. Define the system boundary. i.e. What is within your control, or interacts with it, and therefore the subject of the model.
3. Document the key metrics for success. E.g. what are the things we are having problems with now, are concerned about, or will use to gauge success. Common examples are response times, cost effective use of staff and other resources, capital cost of storage and other infrastructure. Having chosen the metrics that will guide you as to the things that will flow round your model e.g. flow of money, data, material etc.
4. Draw the principal causal loops that relate together the main components of the system.
5. Analyse the system hierarchy. Systems are too complex to model them as one large black box – instead we look inside the system and gradually drill down the layers. This allows different disciplines in the business to contribute to, understand and validate that perspective with which they are familiar e.g. Business to business/customer interactions, business processes, resource management (people and technology levels and availability), and technology infrastructure.
6. Model each of the layers in the system and their interactions using a Systems Dynamics methodology.
7. Build the model with software that can run a simulation.
8. Validate the model by running through known, or historic, scenarios.
9. Use the model to simulate chosen future scenarios.
10. Interpret the results of the simulation and make better business decisions.

The time and effort in the above may look daunting, but even a simple model should bring useful and lasting benefits that far outweigh the initial outlay. The caveats are that the business analysis must be relevant and accurate enough for the model to be validated, and that the design of the model must be done by someone with a full understanding of the consequences of the components on the SD structures used in the model. A multi-disciplinary team is therefore required to address the Business-IT-Modelling aspects of the problem.

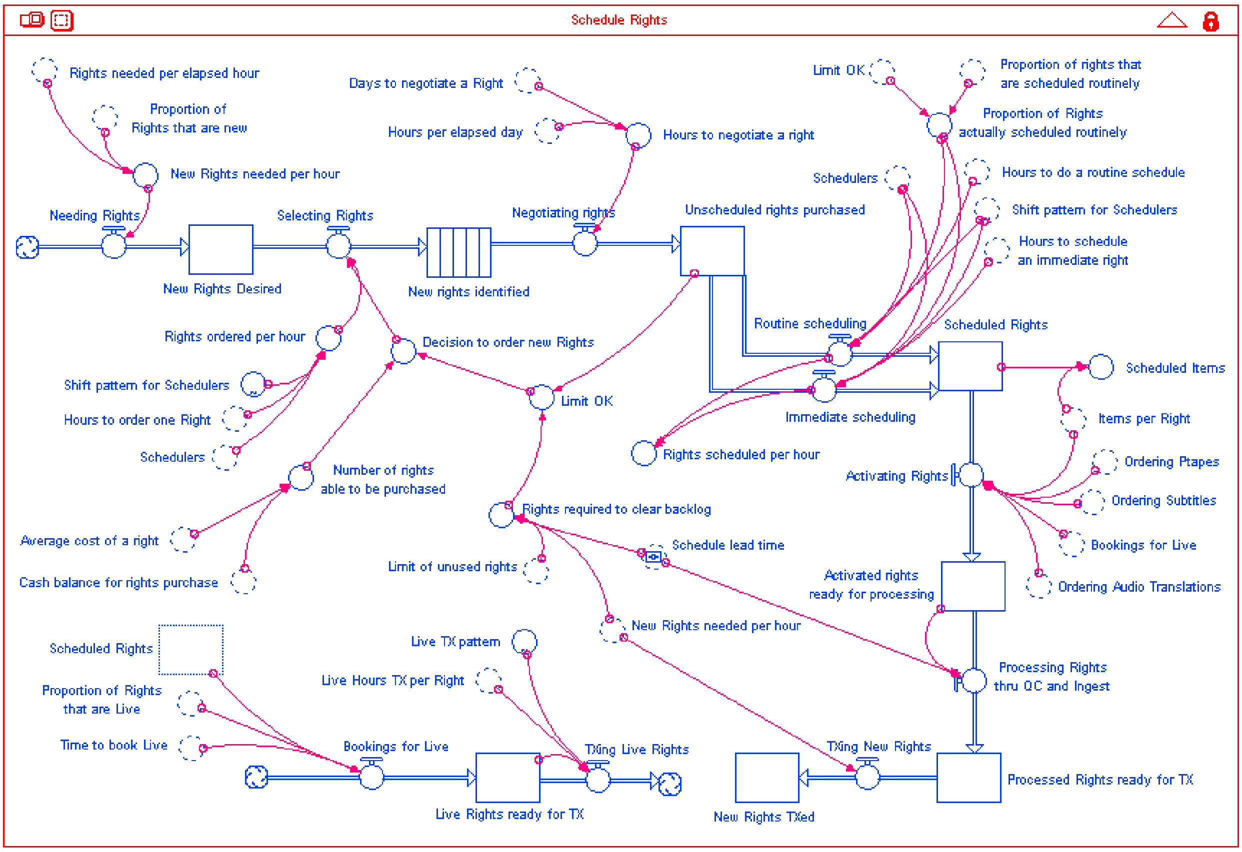
4 EXAMPLE OF A SYSTEM HIERARCHY

Once the problem has been chosen and the system boundary defined then the system may often be considered as a set of layers so as to reduce the complexity of a given layer, and allow each layer to be defined by a more focused set of specialists.

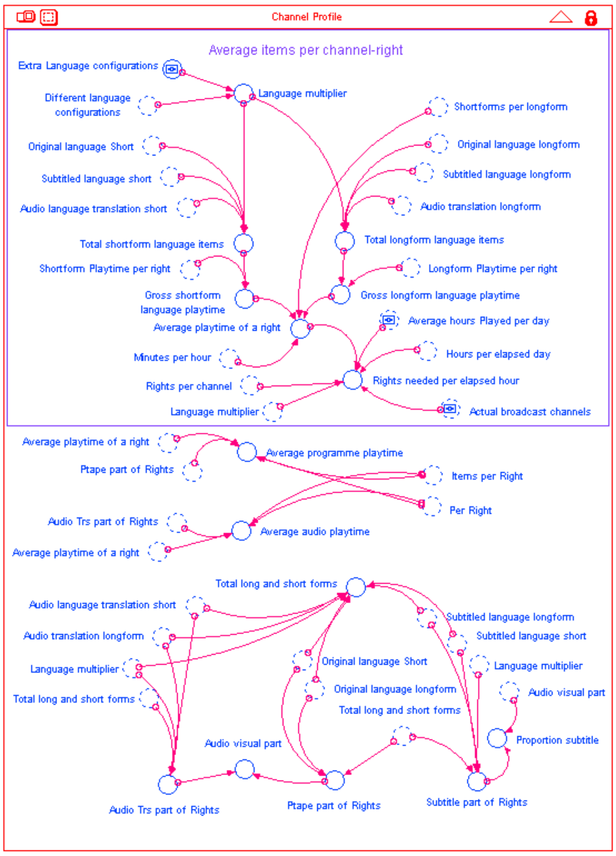
An example of when this has been applied is for a European TV company that wished to expand its business into video on demand. They had allowed for investment in extra archive storage and were concerned whether the overall IT infrastructure could cope with the new business processes and the expected level of customer demand.

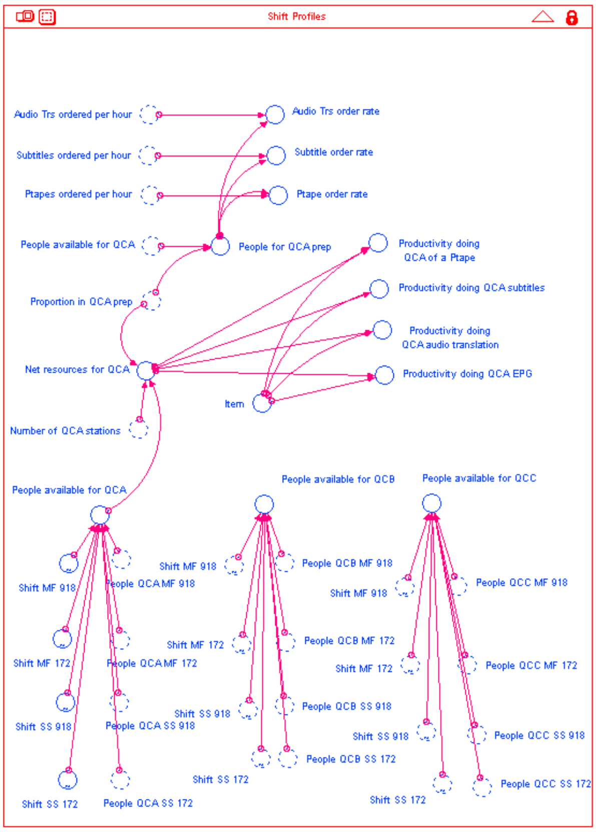
4.1 HOW THIS WAS DIVIDED UP INTO LEVELS (OR SECTORS)

The core activity at the business level was Rights Management. On the basis of what they would like to broadcast or have available on demand they needed the right to show that content. The business processes were modelled as follows:

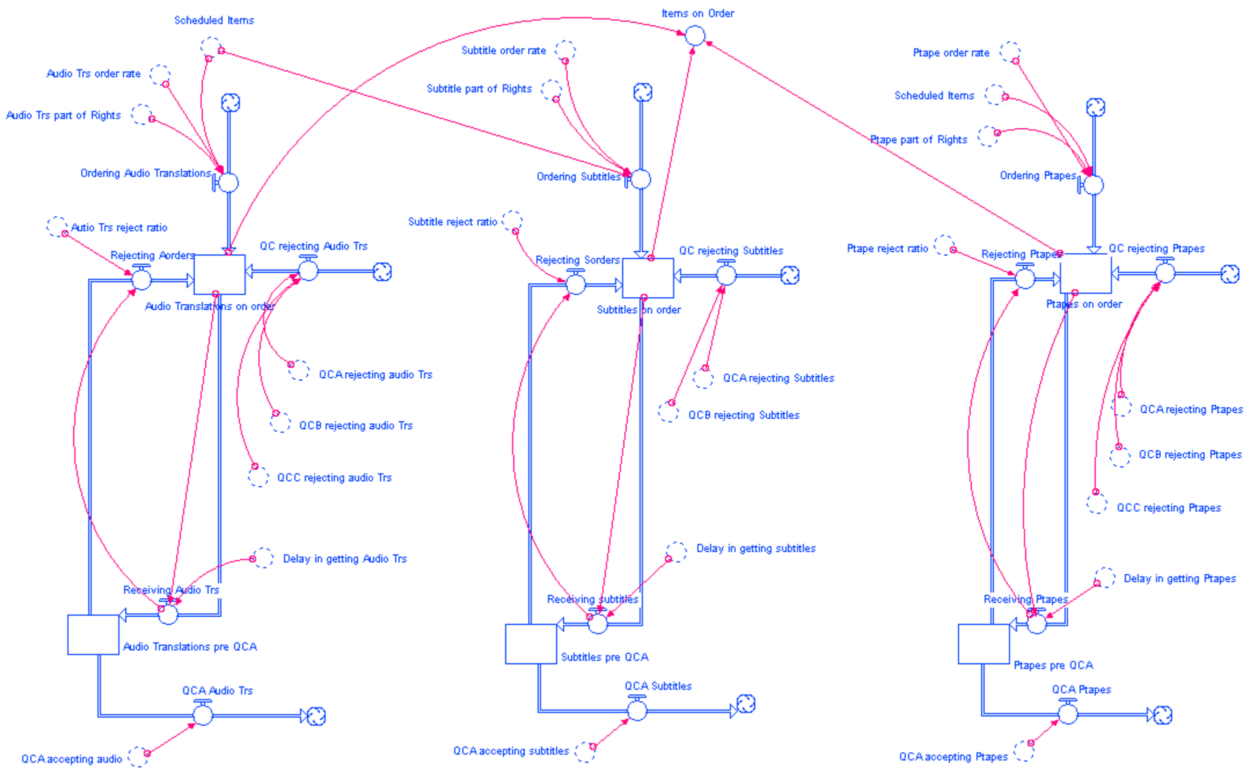


Once a right to content was acquired then that right is modelled by the Channel profile that defined how that right was composed of video/audio/subtitles/etc. There also needed to be a Shift profile that showed when the people were available to do the work necessary in the rights scheduling and all other people orientated work. In effect the shift profile therefore models the people layer below the business processes.



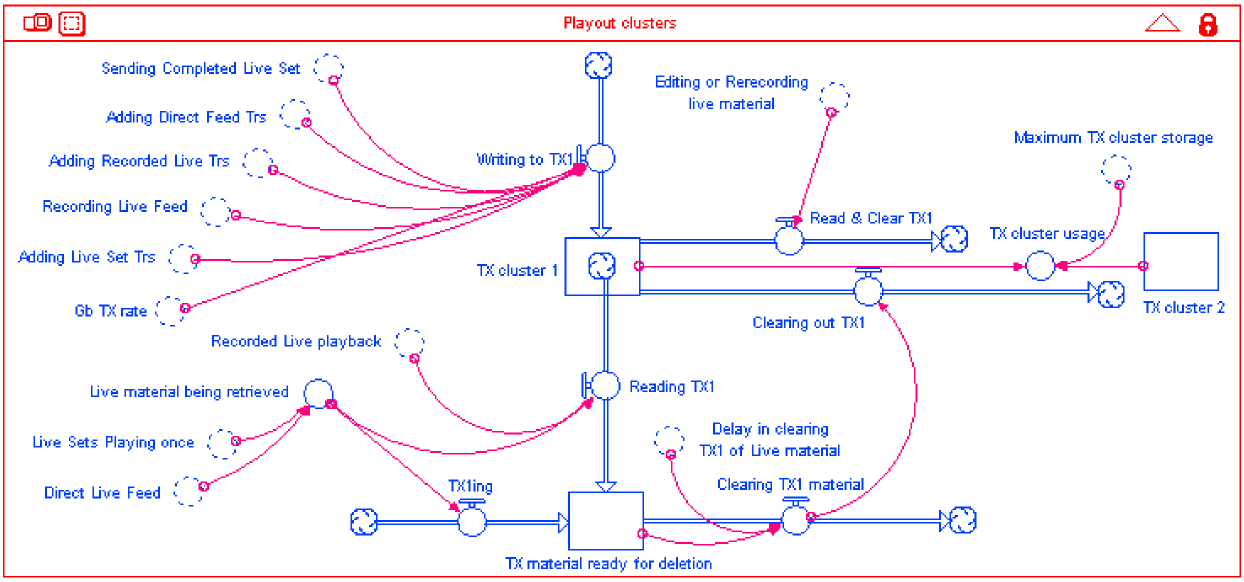


For the content to then be taken into the broadcast company and eventually transmitted there was a workflow that followed the steps of Ingest – Quality control – Playout. Quality control happened at various places and was referred to as QCA, QCB and QCC.



QC preparation steps to validate the quality of incoming audio tapes, subtitles and programme tapes.

As well as the people tasks such as those done during QC there were the computer tasks done by specialist hardware such as the Playout clusters.



By modelling the Business processes → People tasks → Hardware activity it was possible to quantify what the loads, usage, peaks and troughs were for every component in the system. Thus if the business scenario and rules were changed then the effect of that could be seen on the people and equipment and business finances.

4.2 WAS IT WORTH IT?

4.2.1 The effort involved

The SD model was built using commercially available simulation software that was linked into spreadsheets that described the business, people and equipment for a given scenario. Building the model took about 3 months for a team of 1-4 people, or a total of 25 man-weeks.

4.2.2 The outcome

Using the model to simulate various future situations tested two key capital investment decisions. The first was the question of when the existing archive storage needed to be extended, and therefore when it was necessary to spend in the region of $750k. The model predicted in the October that the capacity would be exceeded on 17th January the following year and in fact it was 20th. The model therefore confirmed the timing of that original investment giving confidence that the capital had been employed at the right time, and that the need to extend storage was real.

The second situation was to check if the $600k earmarked for extending the hardware would in fact be required when the business expanded into its new product offering to customers. The model was used in various configurations and it was determined that the whole of the $600k could be avoided if the existing hardware and network infrastructure were re-configured.

By getting the timing and investment decisions right the model paid for itself within 18 months. More modest models, with a simpler problem scope, usually have a faster payback.

5 RECOMMENDATIONS

System Dynamics can assist you in solving all the following problems:

- Spending too much time fire-fighting and applying fixes that fail
- Trying to avoid bottlenecks and other operational problems
- Wasting resources by setting safety margins or contingencies that are too large
- Having a growing business but limiting that growth by under investment
- Deciding what size and capacity is required for the various items of IT equipment and infrastructure
- Not knowing what unexpected side effects may occur when you do planned maintenance downtime

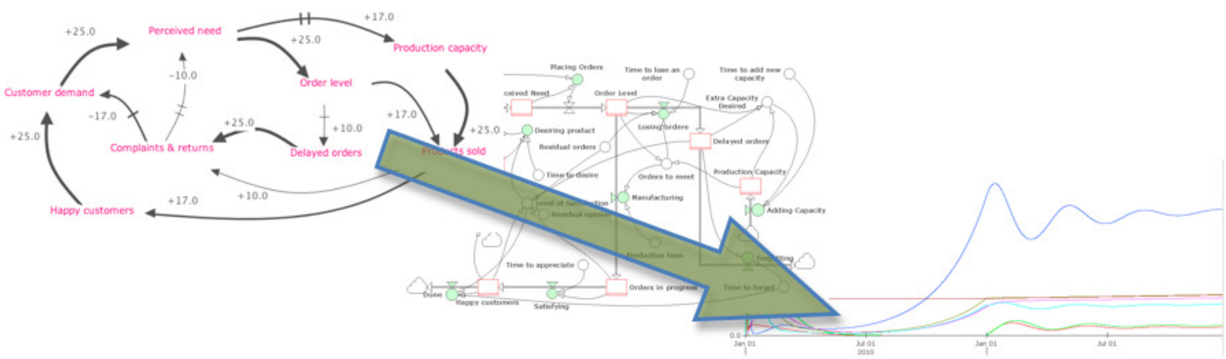
In summary therefore, System Dynamics can save you time, money and effort and help to make better-informed investment decisions.

6 NEXT STEPS

To make SD one of the business tools that you should use, consider the following points:

- Are you about to embark on a change program that involves new IT infrastructure?
- Do you have confidence that the specification of the components is adequate or necessary?
- How will you know when to allocate people and resources so that you minimise downtime, avoid delays and get the correct balance in staff and equipment usage?
- Are you familiar with how to define and deploy a multi-location resilient data system?
- What database / hardware / vendor should we choose – their products all look similar?
- If we change those business rules and goals will it have the intended results or end in disaster?
- What metrics or events should we look out for to trigger contingency responses so that we maintain our service levels?

SD can improve your confidence and understanding when answering these and other questions.



7 FURTHER READING

An Introduction to Systems Thinking – Ithink
Publisher: High Performance Systems Inc, Publication date: May 2001 ISBN 978-0-9704921-0-4

Business Dynamics
Author: John D. Sterman, Publisher: McGraw-Hill Higher Education,
Publication date: 1 December 2000, ISBN 978-0-07-117989-8

Strategic Modelling and Business Dynamics: A Feedback Systems Approach
Author: John Morecroft, Publisher: John Wiley & Sons, Publication date: 13 July 2007,
ISBN 978-0-470-01286-4

The Fifth Discipline
Author: Peter M. Senge, Publisher: Transworld, Publication date: July 1990,
ISBN 978-0-385-26094-7

The Limits to Growth: The 30-year Update
Authors: D.H. Meadows, Dennis L. Meadows, Jorgen Randers,
Publisher: Earthscan Ltd, Publication date: 3 November 2004, ISBN 978-1-84407-144-9

http://en.**wikipedia**.org/wiki/System_dynamics

SD simulation tools
The three most popular tools are: Vensim, Powersim and iThink. Their websites are:
www.vensim.com , www.powersim.com , and www.iseesystems.com .