Management Decision Support Simulations for Technology Investment Planning

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Abstract

Today's investment decisions in the production industry require - as this industry becomes more and more integrated by information systems - a careful long-range planning. Investment projects have to be seen within the network of their environment, and their interdependant impacts can be assessed in a systematic investigation, as part of a Technology Strategy. Furthermore a Systems approach helps to clarify the complex process of Technology Innovations.

Systems thinking to support the definition of Technology Strategies

Over the last years some enterprises gained competitive advantages by shifting successfully to new technologies. Others carried the burden of significant investment expenses, leading to high fixed costs, without any economic advantages, weakening the company's competitive strength.

However, uncertainties about the economic future will never be cleared totally,[1] but a systems approach will at least give an insight into the interrelations of the underlying structures, which will respond to the changes provocated by the strategy decision, and help to understand the system, i.e. the enterprises past, actual and future behavior. So, a systems thinking based assessment of the decisions impacts already in the planning stage will help to reduce the financial risks as far as possible.

SHORTFLEX - a System Dynamics project to assess the value adding potential of different Technology Strategies

In 1986 the "Verband Deutscher Maschinen- und Anlagenbauer" (VDMA) and the "Industrieseminar der Universität Mannheim" (ISM) agreed to set a project on how to illustrate the economic efficiency of computerized technologies in the manufacturing industry.[2] The intention was to create a method to assess the value of higher production flexibilities, reduced inventories and shorter job execution times.

For that purpose, a System Dynamics model was designed, which attempted to translate the - so far mostly blue-sky - conjectures about the value-adding potential of technology innovations into more practical business numbers.

The basic requirements defined as the model's task are shown in Fig.1

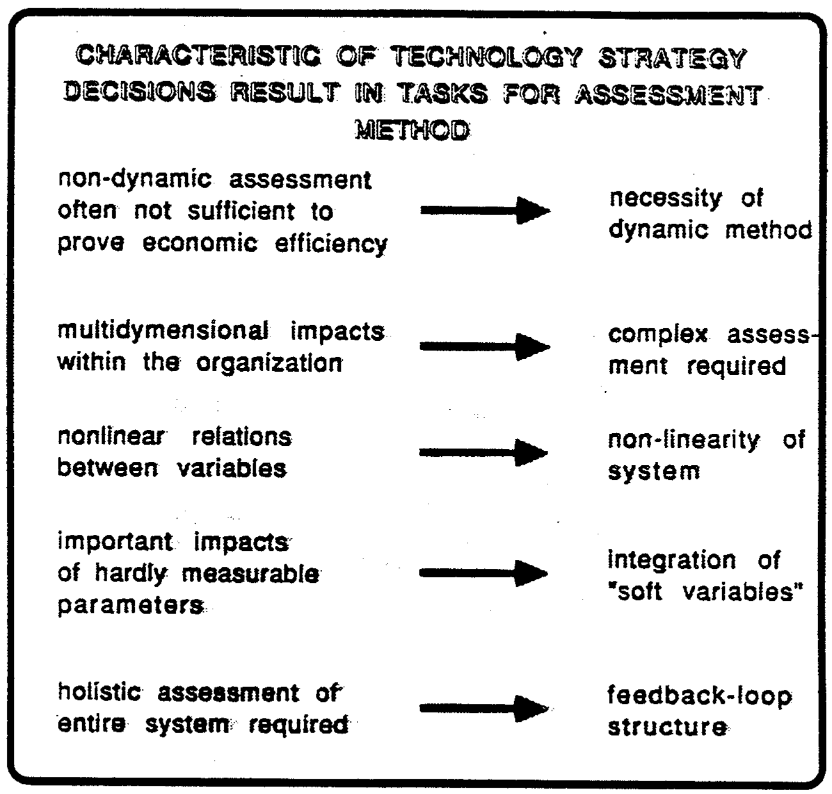


Fig.1: The basic requirement to develop a Technology Strategy - a problem for System Dynamics

The model should provide a vehicle to generate a technology strategy that would be successful under possible "uncertainties", which might range from shifts in consumer demographics to labour unions enforcing shorter workweeks and governmental measures, i.e. change in taxation rates. It should propose ways for a company to meet it's long-range goal and increase it's competitive advantage under which ever conditions turn out to prevail, and finally determine an economic advantageous and technical possible solution, paying attention to organizational aspects as well.

The other main issue was to clarify the feedback-relationships "under the waterline" within the system, for example those between production schedule and inventory, which are often underestimated. The attempt to adjust the production to fluctuating order-rates leads usually to internal amplifications of such external oscillations within the organization, and results in production schedules rapidly changing between overtime and shortwork weeks. This avoids an adequate long-range planning and makes an economic allocation of financial ressources more difficult.

This long-term effect, that a firm's demand for capital fluctuates far more than the demand for the goods produced with that capital stock was first treated formally by Frisch and Samuelson and is known as the multiplier-accelerator theory of investment, which has already been investigated and discussed by John Sterman in several papers.[3]

In Fig.2 the basic structure of the DYNAMO-model shows that it's design of different sections, representing the

- Technology section, the
- Market section, the
- Labour section, the
- Materials handling section, the
- Production section, the
- Cost-calculation section, and finally the
- Financial section,

which includes the financial restrictions about the models investment decisions, such as liquidity has to be guaranteed at all times.

These sections, everyone delineating a model within the model, are driven by internal feedback-loops representing the innerdepartmental decisions and linked together with external loops to the main model, describing the interdepartmental decision making process.

The model's behavior was validated by empirical studies in the production industry, mostly in plants of the machine-tool and automobil

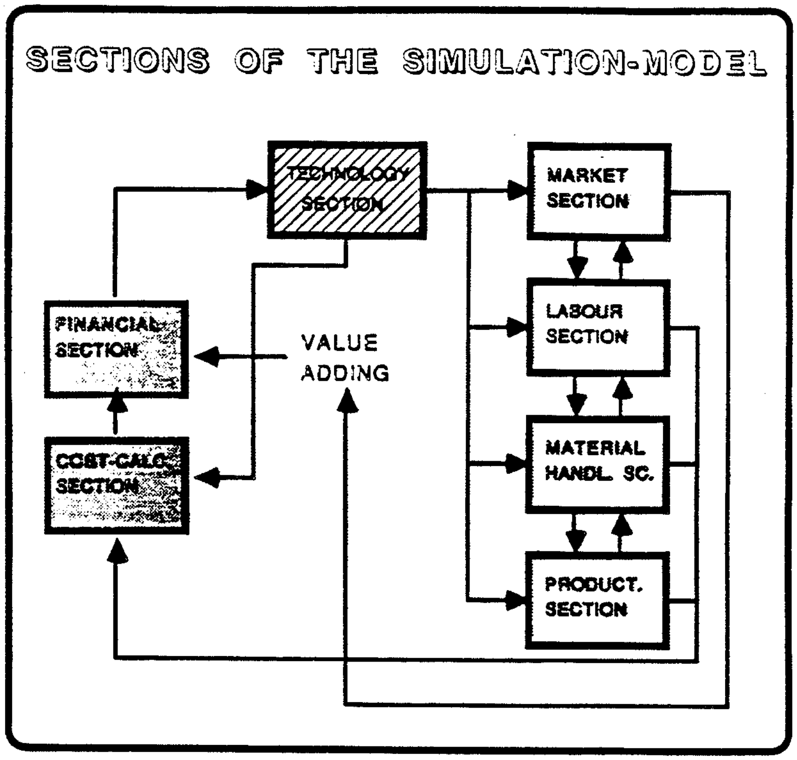


Fig.2: The structure of the DYNAMO-model SHORTFLEX

industry. The presentation of the model convinced many people by the capability of the method. But despite the performance of the model, it was considered more as an academic solution, since it could only be handled by a System Dynamics and DYNAMO-experienced person - a requirement, which so far is not met by too many managers at all.

STRATECH - a participatory simulation to illustrate the economic impact of manufacturing innovations on production, inventory, capacity and profit

In consequence, the next step was to make the model's behavior easier to interpret and it's application easier to handle for the user, with the intention to serve as a meaningful basis for business decisions.

So, based on the original DYNAMO-model, a STELLA-version was designed on a level of higher aggregation, focusing mainly on the

- materials flow (including inventories), the
- capacity (capital stock) and the
- order flow.

The structure of the STELLA-model is shown in Fig.3, the arrows describe the information flow to generate the systems decisions, while the broken lines represent the decisions, which later will be required by the participant. For the reference-calculation, these decisions were made by the computer as well.

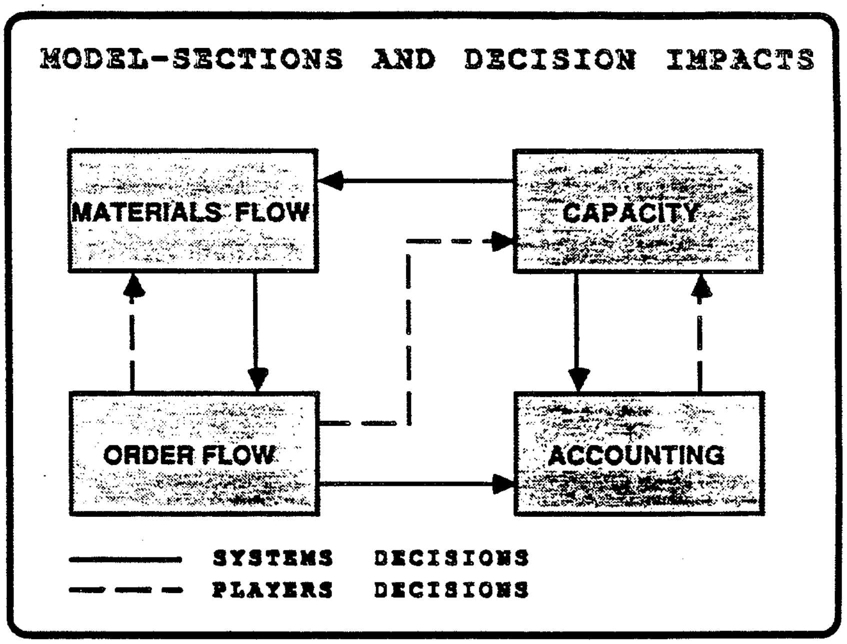


Fig.3: The structure of the more aggregated STELLA-version STRATECH

The simulation examined three different technology strategies under the same external economic conditions:

- Every strategy had to guarantee the permanent supply of all it's **Orders**.
- The **Desired Production** is determined by the anticipated, smoothed demand in history, taking into account the systems delays, i.e. the **Job Execution Time**.

- **Desired Inventory** is calculated on a "savety basis" to ensure permanent ability to deliver, dependant on the flexibility of the manufacturing system.
- **Capacity Adjustment** requires in advance-planning, since it is characterized by significant delays.
- The **Orders** are represented by a fluctuating graph, including an increase in basic demand in period 20.

The three technology strategies are characterized as:

Strategy 1: "low tech"-strategy, characterized by inflexibility in manufacturing, long **Job Execution Times**, low **Fixed Costs per capacity unit** and relativly high **Variable Costs**.

Strategy 2: "middle tech"-strategy, including medium flexibility, higher **Fixed costs per unit** and lower **Variable costs** than strategy 1.

Strategy 3: "high tech"-strategy, characterized by high flexibility in manufacturing, small economic batch sizes and short **Job Execution Times**, but requiring high investment expenses. This leads to high **Fixed costs per capacity unit**, and relatively low **Variable costs**, due to automatisation of the manufacturing process.

To ensure equal chances for every strategy, the basic calculations will generate exactly the same economic results - the **Cummulative Net Profit** - if the order-rate would be stable at it's average level. So, any different results between the strategies are due to external fluctuations of **Orders** and their impacts due to internal amplifications by the system.

The most important results of the simulation are illustrated in Fig.4 through Fig.8. Fig.4 illustrates, how the fluctuations in **Orders** are amplified by the system, dependant on the length of the **Job Execution Time**. The delayed response - representing the systems inflexibility - leads to accelerated amplifications down the supplyline, which for Strategy 1 result in consequences even in the **Capacity** section. Though the maximum order-rate is always below the initial capacity, the system tends to capacity investment activities.

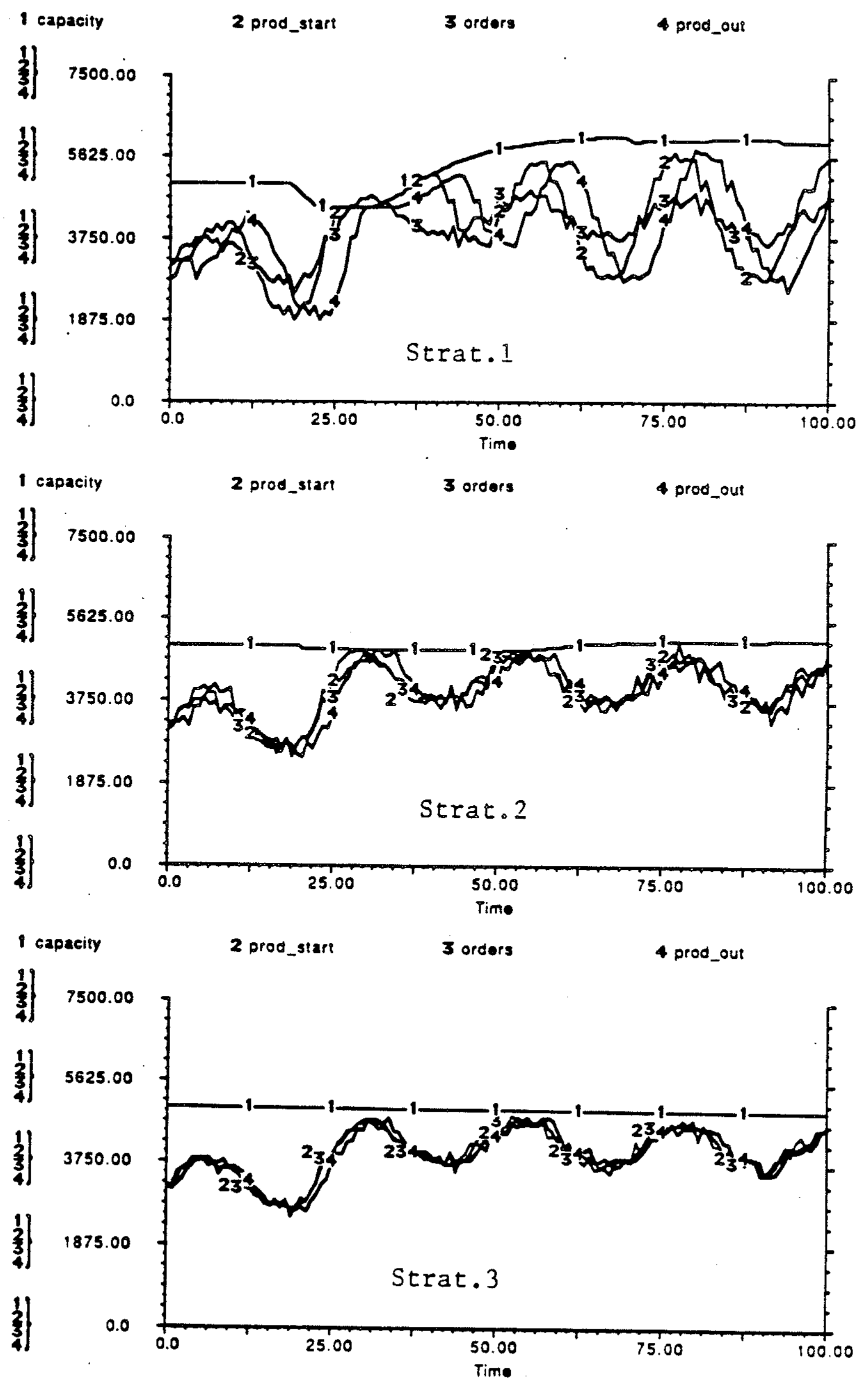


Fig.4: Orders, materials flow and capacity

In Strategy 2, the effects of fluctuating **Orders** on the capacity planning are already smoothed very well. However, the flexible Strategy 3, which assumes that the **Job Exection Time** is as short as the **Desired Delivery Delay**, illustrates the equity of **Orders**,

Production Start and **Production Output**. In this scenario, capacity adjustments are not necessary at all. This, in fact helps long-range planning to be more reliable. Plotted in terms of average **Capacity Utilization**, Fig.5 shows the smoothing effects of higher flexibility in manufacturing.

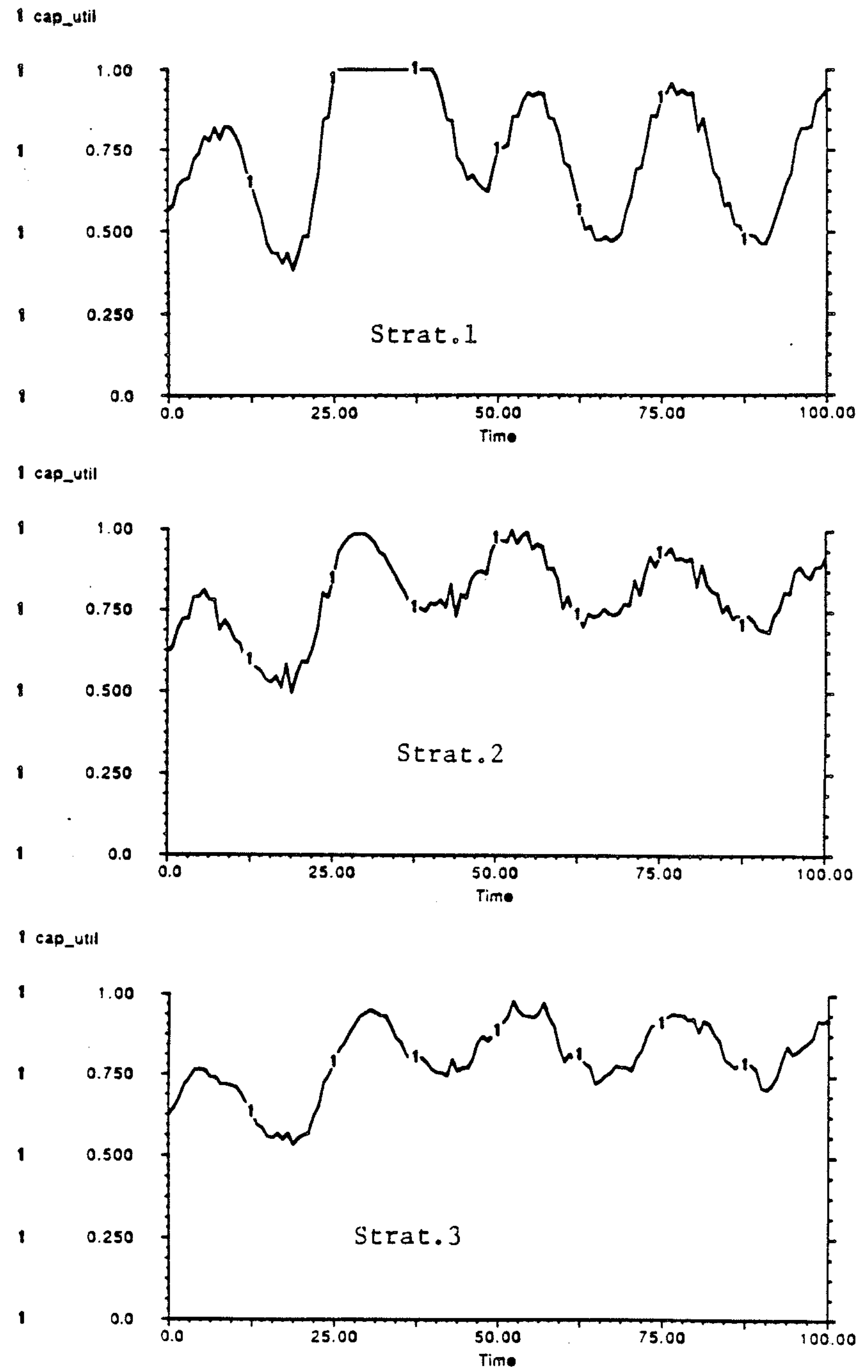


Fig.5: Capacity utilization

Fig.6 gives an insight, how the delayed response of **Production Start** to changing **Orders** leads to long-range amplifications in the manufacturing system. This effect will be reduced, dependant on the decreasing length of the systems time delay - the **Job Execution Time**.

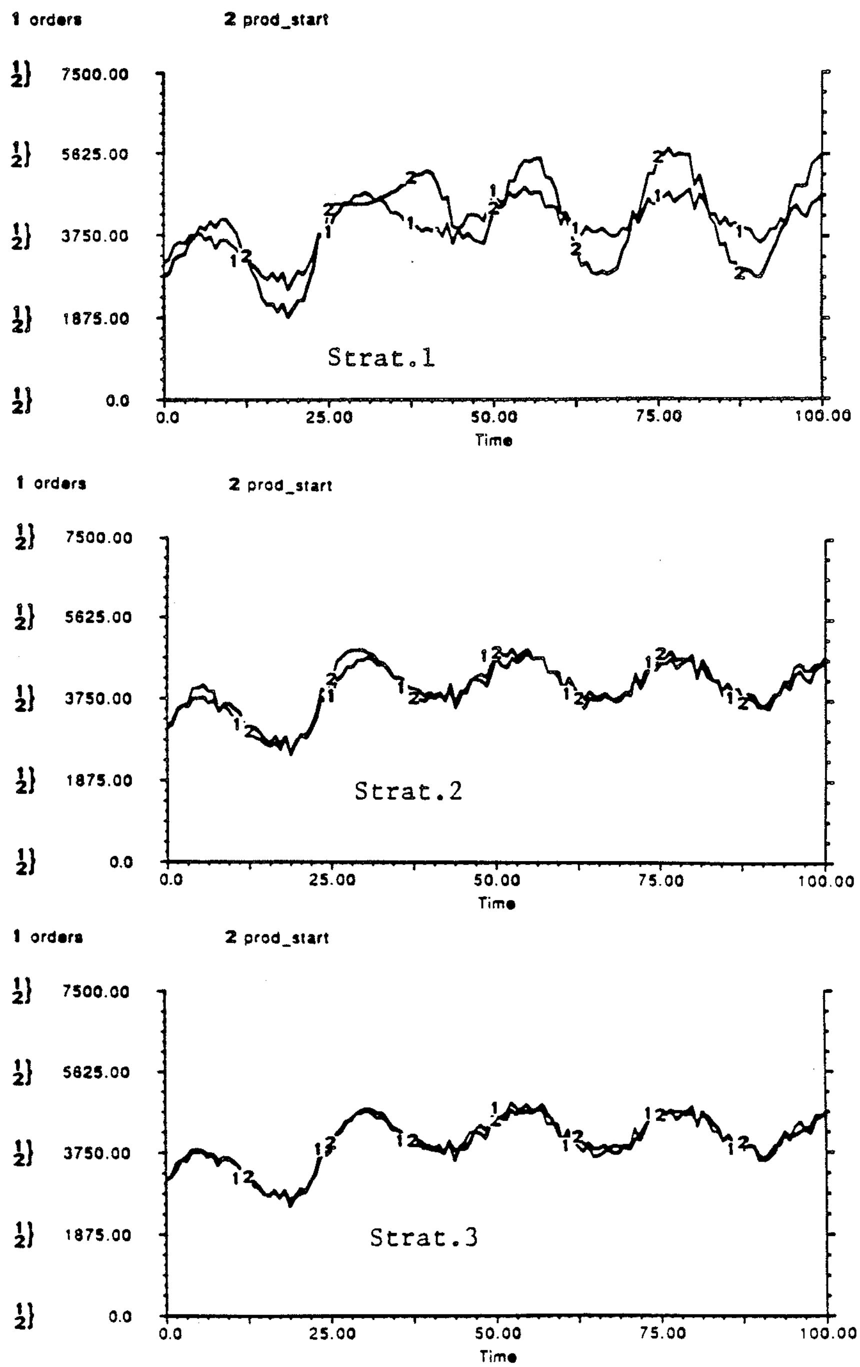


Fig.6: Orders and production starts response of system

The main task - to serve all the **Orders** in time - is met in all scenarios as shown in Fig.7. **Backlog** represents the **Orders** due in the calculation period, which are served by **Sales**. Except for some very little "Noise", both graphs are equal. Hence, the ways to reach this goal are different, depending on the actual strategy.

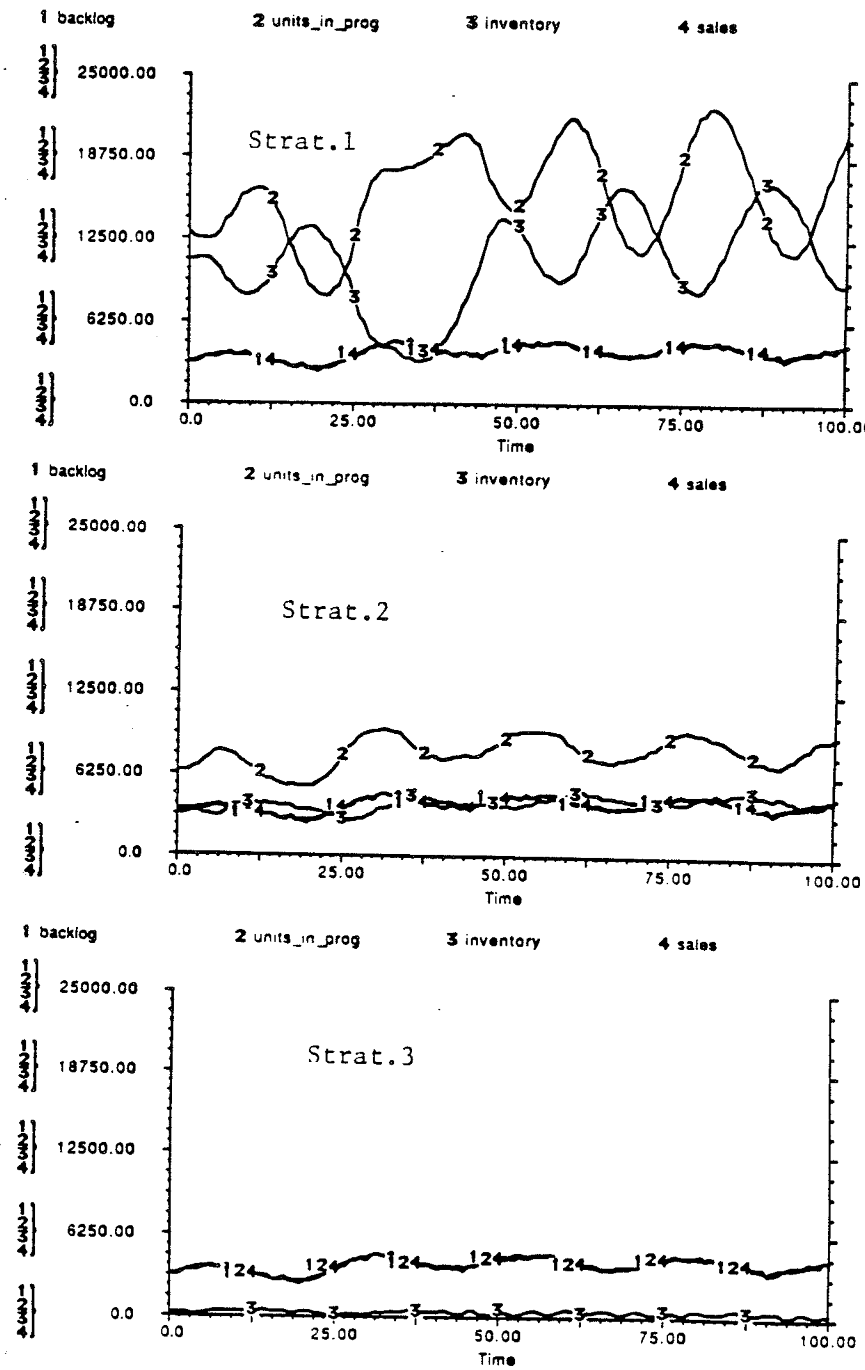


Fig.7: Process of serving orders with different strategies

The inflexible Strategy 1 is shipping the **Sales** basicly out of stock, which coveres all the expectable fluctuations until the production catches up. On the other hand, **Units in Progres** overshooting demand are stored, a strategy which leads to high level average **Inventories**. Strategy 2 is able to reduce **Inventories** significantly, while the flexible Strategy 3 is almost able to abondon it's **Inventories** at all. **Units in Progres** equals the **Orders** to be served as well as the **Sales**, illustrating the fact that **Sales** are directly shipped off the line.

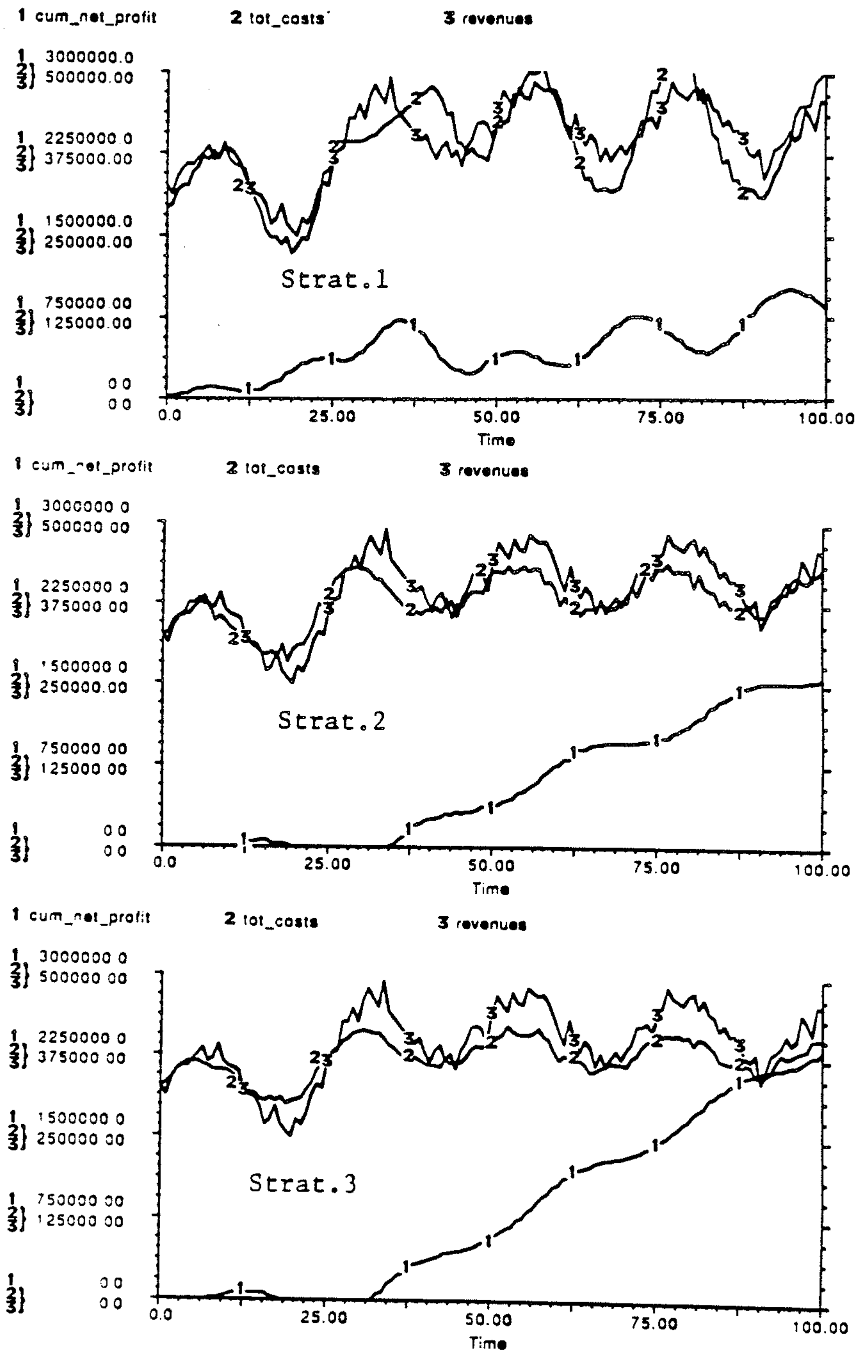


Fig.8: Economic results

Finally, Fig.8 provides a general view about the economic efficiency of the different strategies. None of them is really unsuccessful, but the advantage of at least the partly flexible Strategy 2 is significant. The fact, that the economic result in Strategy 1 tends to fluctuate between losses and profits, while the other strategies seem to provide more stable results, may as well contribute to a more solid basis for long-range planning as the stabilization of the **Capacity Utilization** (Fig.5).

MICROWORLD-interface connects STRATECH to the user

This STELLA-model was linked to a MICROWORLD[4] interface, which is a handy tool to provide a meaningful connection between an unexperienced - as far as System Dynamics and STELLA is concerned - user and the model. By cutting off the decision making loops within the model (Fig.3), the STELLA/MICROWORLD-model is transformed into a participatory simulation game.

To run the game, the participant has to make three basic decisions, one on each level of

- The production planning schedule **prod_start**, representing the short-range, operational decision.
- The capacity acquisition **ordered_cap** as a middle-range decision, and the
- "flexibility" of his manufacturing process, described by the length of **job_exe_time**, as the long-range, strategic decision, which will determine his burden of fixed costs.

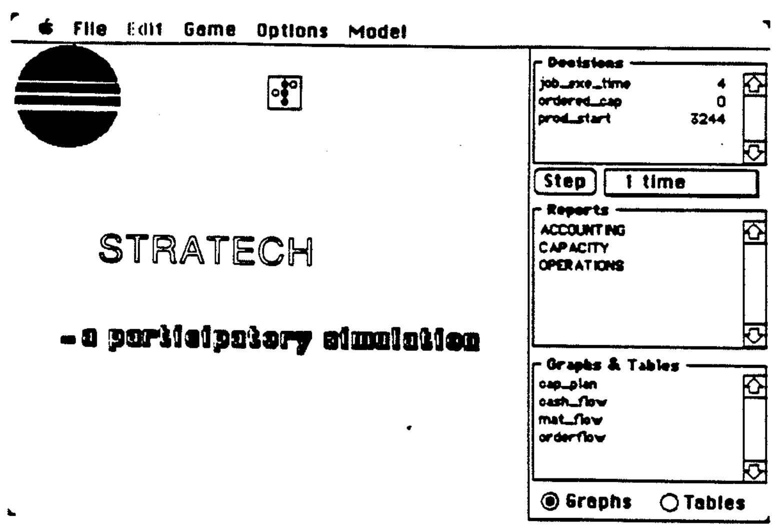
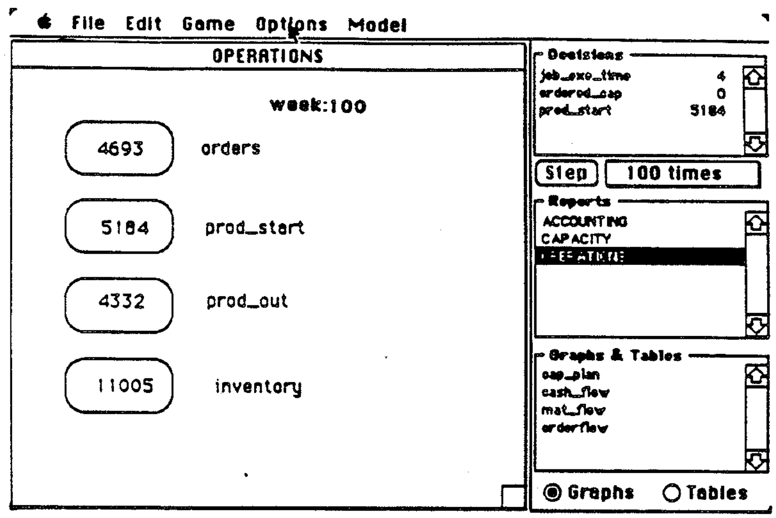


Fig.9: Microworld spreadsheet

In addition to the external decisions required by the player, the spreadsheet shown in Fig.9 provides the player with the information he needs to make his decisions as well as it illustrates the consequences of these decisions.

The information **Reports** (Fig.10) and **Graphs & Tables** (Fig.11) focus on the description of the relationships between manufacturing flexibility and the oscillation in desired production, actual production and inventories. They emphasize the crucial impacts of delays in the system and between investment decisions and their actual economic effects for the firm.



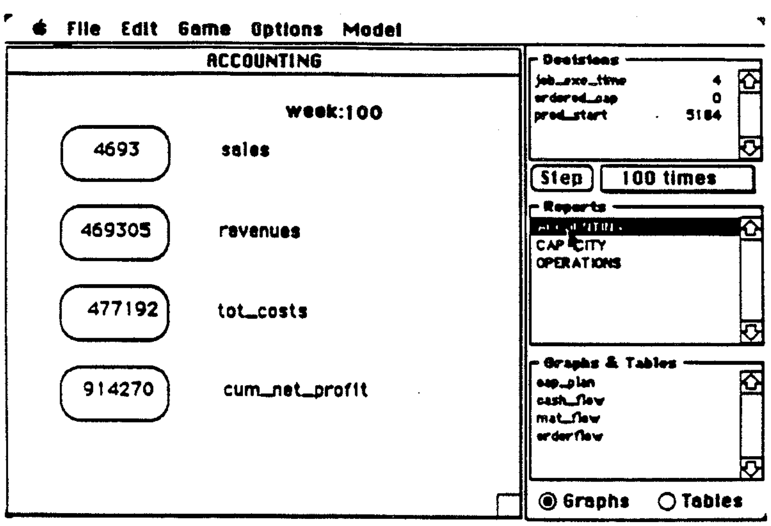


Fig.10: Reports of MICROWORLD to the participant

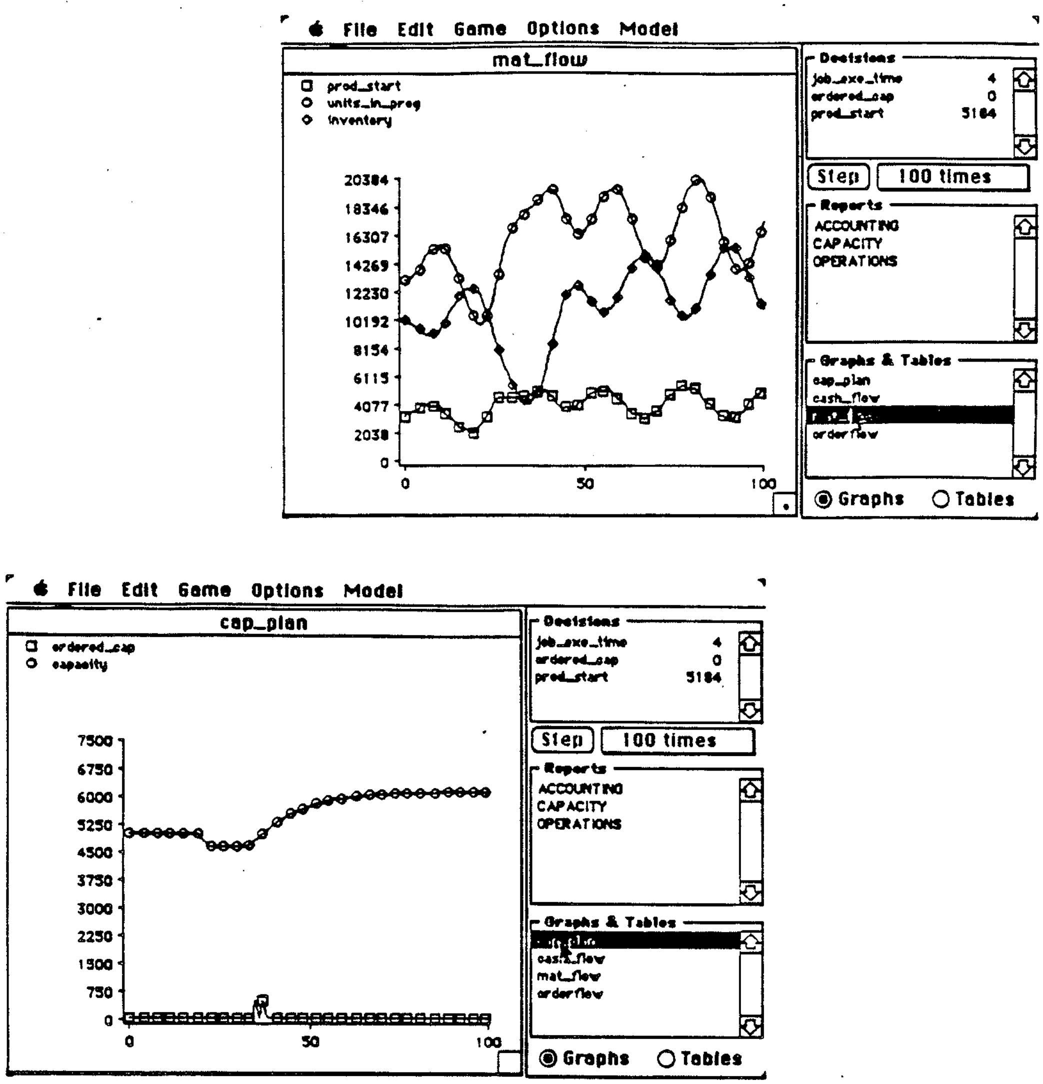


Fig.11: Graphs &Tables show consequences of paticipants decisions

So, this participatory simulation assesses the

- technological,
- organizational and
- economical

implications of a certain Technolgy Strategy. It may provide - in a more sophisticated version, which is still in the process of being developed - a learning laboratory to get a feeling how to manage the innovation process in the computerized enterprise, and to handle difficult markets successfully by anticipating their fluctuations through the application of the appropriate technology.

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3 Sterman, J.D.: Misperceptions of Feedback in Dynamic Decision Making, pres. at the 1986 Judgment/Decision Making society meeting, New Orleans, LA.

4 Diehl, E.W.: MICROWORLD user's manual, Cambridge, MA. 1989.