10 Networked supply chains

10.1 Introduction

10.1.1 In the previous chapter we addressed the market as a complex dynamic system, displaying a more orderly underlying structure then could be expected looking at the phenomenological expression of buying behaviour. The rich solutions space modern clients are apparently expecting, as well as the lack of predictability of their requirement outside this specificity of the moment, requires a supply chain which is capable of arriving at a much wider variety of solutions and can be configured under direct control of the client rather than based on management control as a result of planning information. In this chapter we will address the principles of such supply chains.

10.1.2 Apart from the reasoning that conventional solutions routinely applied in companies at this moment fail to address the fundamentals of the problem, a lot of attention in this chapter is devoted to the mass customisation theorists. The reason for this rather extensive discussion of mass customisation is that on the one hand, in recognising the signs, the founders of mass customisation have contributed a lot to the identification and description of the fundamentals of changes taken place in the market place. Yet on the other hand, in thinking through the consequences, they fall short in drawing the full conclusions of their observations.

10.1.3 As these consequences are in current literature taken in a rather piecemeal fashion, we attempt to bring all of these views together in a coherent framework, which enables us to understand the various approaches and when and why they might be relevant.

10.1.4 At the end of the chapter we address the risk, which is inherently present in all networked systems, of non-linear propagation of disturbances. This phenomena can cause networked systems, in this case supply chains systems, to become beyond control and end in complete chaos. This is an important topic for further research, as this phenomenon does in practice limit the extent to which the benefits of atomised self-organising supply chains can be realised.

10.2 Supply chain configuration

As differences between clients become the driving force behind value creation, and as such differences are emergent, non-linear phenomena, supply chains cannot be configured based on prediction and forward planning.

10.2.1 As stated, in all developed societies there is a growing tendency that individuality in consumer behaviour manifests itself as an ever-increasing erratic and unpredictable buying behaviour. Western companies are facing the choice to take this erratic behaviour seriously and turn it into economic advantage, or else to adjust their cost structure to that of their competitors from countries with a relatively lower standard of living (mainly from Eastern Europe and South-East Asia). Maximisation of productivity in the existing industrial supply and organisation structures is based on a maximum re-use of knowledge and material assets. They reach their maximal economic potential in a world in which consumer behaviour can reliably be predicted and large homogeneous batches of the same product can be manufactured

10.2.2 Industrially organised supply chain processes pose a fundamental problem for the economics of the individualised part of the chain. As economies of scale are linked to homogeneous (batch-produced) quantities, the process efficiency will erode under conditions of complete individualisation. Within the paradigms of industrial organisation, mass-individualisation will therefore carry prohibitive cost penalties.

10.2.3 In Chapter 4.6 we argued that the industrial way of organising supply chain processes leads to prohibitive complexity costs under conditions of advanced heterogeneity. Multiple examples were given of situations in which the impact of these costs on chain productivity is already very substantial, questioning the fundamentals of the Taylorian structure of such chains:

- Furniture;
- Food retail;
- Tailored suits;
- Food product manufacturing;
- Industrial specialities;
- Car manufacturing.

10.2.4 All of these examples do not originate from exotic, poorly managed companies who have a relative backlog in relevant knowledge and investment level. In almost all cases, they concern market leaders in their own segment. These leaders are (still) financially successful because their direct competitors in this area are certainly not doing any better (often even worse) and in many markets they can still charge their ineffectiveness to the client. Yet, such a cost structure is very vulnerable to competition. Furthermore, due to the ever-increasing pressure of heterogeneity and unpredictability the problem will only grow, until the costs of complexity become prohibitive as they can no longer be charged to the client.

10.3 The inadequacy of current solutions

Most solutions that are currently available, pass the consequences of unpredictable heterogeneity on to the customers. This is done by extending delivery times, by fitting demand with supply through the force of assortment rationalisation, or by maintaining excessive stocks that cause price penalties to the customer. None of these is acceptable or possible under conditions of infinite heterogeneity. In practice, the best compromise that can currently be reached, is limited by the marginal cost of advanced, flexible, production- and planning/control technology versus the value premium that individualisation commands in the market.

10.3.1 The consequences of an increasing heterogeneity (through individualisation) and the decreasing predictability (through erratic behaviour) are currently addressed by means of intermediate stocks (which keep the batch size in the supply chain intact), prolonged delivery times (‘make-to-order’, which is the ultimate predictability), reduction of assortment variety (which increases batch sizes) and the application of modern technology (which decreases the marginal costs of heterogeneity). The limitations of these alternative methods will be discussed below.

Intermediate stocks

10.3.2 A common response to chaotic market behaviour is described by Day (1983). He states that apparent chaos in markets may result in the evolution of 'un-equilibrium mechanisms'. These are mechanisms that buffer the effects of unpredictable fluctuations in behaviour and allow a system to function in conditions of un-equilibrium. They include inventory-holding intermediaries such as retail stores, banks and financial intermediaries that regulate the flow of purchasing power, ordering mechanisms with accompanying backlogs and variable delivery delays, and insurance systems. Hibbert and Wilkinson (1994) comment that this runs counter to just-in-time systems that seek to reduce buffer stocks. Such systems would involve closer co-operation among the companies involved. Furthermore, they argue that this co-operation may reduce the times that the company over- and undershoots the equilibrium supply levels and may thereby prevent complex oscillations and chaos. Absorbing the consequences of heterogeneity by creating intermediate stocks does not seem to provide an adequate answer to cope with unpredictable heterogeneity.

10.3.3 Pine, Victor and Boynton (1993) provide an example of a company that set itself the objective of being able to deliver a custom-built mainframe within a week. It did not achieve this objective through any mass-customisation technique, but through stocking inventory for every possible combination that customers could order. The company ended up with hundreds of millions of dollars in excess inventory.

10.3.4 Similarly many PC manufacturers have recently written off heavily on stocks of finished product and components. These stocks were used to buffer the production system from consumer demand, as customers who are looking for a PC will not accept a long delivery time. Ideally they want to take the equipment home immediately and their willingness to pay for this service is very low. This unpredictability of consumer behaviour, coupled with the continuous launch of new products by component manufacturers, makes stockholding an increasingly risky activity.

Extending delivery times

10.3.5 Lengthy delivery times as a solution for unpredictability is applied e.g. in the car industry, the furniture and the kitchen industry. Actual delivery times bear no relation to real production time. This huge difference is the result of having to convert unpredictability into the planning of an industrial supply chain. In this way industrial supply chain processes can remain largely untouched and economies of scale can be maintained, at least with regards to the primary supply costs. In fact, the client's unpredictability is transferred to himself through the creation long delivery times, evidence of an inability to create real responsiveness in industrial supply chains. If it takes 18 hours to build a car and transport throughout Europe maximally two days, theoretically it should be no problem to supply a car made to specification within a week. As long as everyone accepts these delivery times and no other supplier offer a higher response level, there seems to be no problem. Yet, at the recent (1997) IAA fair in Frankfurt, the long delivery times were described as the single most important problem the car industry is facing, even as the industry is struggling with a substantial over-capacity. However, the manufacturer within the industry who will be the first to able to break this barrier and really resolve the complexity problem in the supply chain, will gain a very substantial competitive advantage and will force others to radically reconfigure their current supply processes.

Assortment rationalisation

10.3.6 The most radical solution, which is routinely applied, is rationalising the assortment by terminating low volume items from the assortment. By removing those parts of the assortment in the steep part of the complexity cost curve, generally loss making chunks of volume are eliminated, which improves total profitability.

10.3.7 Fuerderer (1996) says:

> *"As most world-class car producers have reached a comparable level of technical sophistication and quality, the cutting edge is the ability to manage the issues of product variety: what type of variety should be offered, in which quantities and how can it be produced at least cost."*

Yet, if demand is unpredictable, how can the type of variety be determined, let alone the quantities? Stannack (1997) states that as for now approaches that encourage diversity are not popular within supply chain management. Most attempts to increase chain co-operation still employ command and control methods, thereby reducing the effectiveness of information transfer between entities in the chain, and limiting the number of possible paths.

10.3.8 Fisher (1997) stresses the importance of adjusting the supply chain to the type of product a company produces. He argues that for functional products (i.e. long product life cycle, low contribution margin, low product variety, predictable demand, low stock-out rate) a physically efficient supply chain is required, while for innovative products (i.e. short product life cycle, high contribution margin, high product variety, unpredictable demand, high stock-out rate) a market-responsive supply chain is needed.

10.3.9 A company can react to such sub-optimal situations in two ways: either it makes the product more functional, or it makes the supply chain more responsive. Procter & Gamble, for example, has been simplifying many of its product lines, because product varieties in many grocery categories (e.g. 28 varieties of toothpaste) dazzle the customer. Fisher:

> *"Toothpaste is a category in which a move […] from innovative to functional makes sense."*

10.3.10 He continues to state that companies also can make their supply chain more responsive by:

- accepting that uncertainty is inherent in innovative products;
- continuously striving to reduce uncertainty by (1) finding 'leading indicators' of demand, (2) using modular design, so that demand for the components becomes more predictable;
- cutting lead times and increasing the supply chain's flexibility;
- hedging against uncertainty with buffers of inventory or excess capacity.

10.3.11 Kotha (1995) argues that firms competing in industries undergoing such transformation find that they are no longer able to compete on the basis of standardised products and services alone. Moreover, in such environments, being ‘world class’ in manufacturing is not enough to sustain competitive advantage. He adds a few important criticisms, however, to the notion that mass customisation is the only viable strategic option for the 1990s, as Pine and others propose. The general prescription that mass production is not a viable strategy in many industries is perhaps too extreme an assessment, because theoretically a firm could pursue a mass customisation strategy in one segment and a mass production strategy elsewhere.

10.3.12 From his case study at NBIC (National Bicycle Industrial Company, a Japanese bicycle manufacturer) it becomes clear that mass-customisation need not be framed as an ‘either/or’ proposition:

> *“Many Japanese firms (and some American firms) have shown in practice that a simultaneous pursuit of both strategies is possible [...]. Moreover, like the NBIC, many firms contemplating mass customization are likely to find that their largest source of revenues (and accompanying profits) is currently derived from exploiting the paradigm of ‘mass production’. Nothing in practice precludes such firms from pursuing mass production in one segment of the industry and mass customization in another.”*

However, he adds that when firms pursue both mass production and mass-customisation, it is prudent for them to adopt the notion of ‘factory focus’.

10.3.13 A mismatch between product and supply chain types, Fisher states, is the root cause of the problems plaguing many supply chains. For instance, a responsive supply chain in a functional product environment is likely to only add to cost, which cannot be earned back because of the low contribution margins and low stock-out rates (e.g. a 10% stock-out rate and 5% of contribution margin mean a contribution loss of 0.5% of sales, a small amount which does not offset investments). Investments in responsiveness will only pay off in an innovative product environment (e.g. a 25% stock-out rate and 40% of contribution margin mean a contribution loss of 10% of sales, a large amount which will be likely to offset investments). On the other hand, a physically efficient supply chain for an innovative product will lead to high losses, due to products being out of stock. To illustrate this, Fisher uses an example of an American car which, taking all options and colours into account, can be built in 20 million versions. Because of the unresponsiveness of the supply chain - it takes eight weeks to deliver the desired custom-built model - at any moment the customer can only choose from about 20 versions (the ones in the dealer’s showroom).

10.3.14 Yet, it would be a simplification to divide the world into ‘commodity’ vs. ‘specials’. Under conditions of extreme (heterogeneous) unpredictability, mass manufacturers will increasingly see their batch quantities shrink. Separating ‘commodity’ from ‘specials’ will create inflexible mass production and expensive specials, reinforcing the paradox of industrial logic.

10.3.15 In summary, assortment rationalisation not only makes it necessary to keep reviewing the variety in the assortment critically, it actually puts the world upside down. In a market in which heterogeneity is the norm, one cannot resolve the complexity problem by the mere elimination of such heterogeneity [i].

Technology shifts

10.3.16 A fourth approach is to shift the complexity border, the bending point of the complexity cost curve, to the left. That way smaller batches can be manufactured and supplied at cost parity level. In the car industry one has been able to reduce the minimal batch size with a factor 10 in ten years' time. These shifts are, however, mostly very technology- (and hence capital-) intensive. Changing the shape of the curve dramatically in may cases implies a complete changeover of supply chain technology, e.g. from printing technology to electronic publishing in the publishing industry. Less radical and more evolutionary changes in process technology tend to push the cost level in the tail as a side effect. Not only does the bulk of the volume incur higher costs, it is a matter of time before a new complexity border is reached, and the problem will emerge again[ii].

10.3.17 Kotha (1995) reminds his reader of Hayes and Wheelwright's dynamic framework of matching a firm's product and market evolution with manufacturing process characteristics. They argued that a customised product was best produced in a job shop environment, whereas standard products were best produced in an assembly line mass production environment. The rationale for this lies mainly in economies of scale due to large capital investments. A trade-off existed between product variety and product cost, between efficiency and flexibility. Kotha however argues that advances in manufacturing automation now facilitate the manufacturing of a variety of products in a connected line flow (i.e. a mass production environment) and, more important, that product variety can now be achieved without the accompanying cost penalty.

10.3.18 According to Kotha there are generally three reasons cited for the transformation from mass production to mass-customisation:

- The emergence of new manufacturing technologies, which changed the economies of manufacturing and removed the factory as a barrier to variety and flexibility;
- The increased pace of technological change and the concomitant shortening of product life cycles that have led to an increased proliferation of product varieties;
- The shifting nature of customer demand for increased product variety, more features and higher quality in products and services.

10.3.19 These shifts are however mostly very technology- (and hence capital-) intensive, which is why they also push the cost level in the tail. Not only does the bulk of the volume incur higher costs, it is a matter of time before a new complexity border is reached, and the problem will emerge again. But apart from that, a very substantial part of the complexity costs arises from indirect activities (planning, co-ordination, ordering etc.) and failure costs (as a result of failing predictions). This problem is one of order, not one of manufacturing technology.

10.3.20 In conclusion it can be said that current industrial processes are essentially inadequate for coping with unpredictable heterogeneity, many solutions suggested in literature will ultimately meet their own limitations. Stockholding is becoming un-affordable from an economic point of view (at any rate they are very risky), delivery time will have to become shorter rather than longer (on the penalty of losing demanding customers) and technology is not only expensive, but adds additional complexity to the underlying processes. The first two aspects are widely known. In many areas solutions are developed to reduce stocks (e.g. efficient customer response in the food sector) and to obtain acceleration in the supply chain (e.g. time-based management). However, one aspect receives too little attention: the consequences of the ever increasing complexity for the costs of direct and indirect processes in heterogeinising organisations. And in the end here lies the key to the creation of business processes which can achieve specials at cost parity. Although by means of Business Process Redesign unnecessary process interfaces and integrated supply chains are addressed, such processes touch the effect of unpredictable heterogeneity only sideways. As long as predictability remains, BPR will achieve important improvements, but it is especially the increasing unpredictability which leads to uncontrollable complexity costs. It proves that in practice these costs are not only very substantial, but cannot be detected from within the existing paradigms, too. It is therefore worthwhile to focus on this problem, make these costs visible and formulate new principles to eliminate these costs rather then reduce them. Or worse, charge them to the customer.

10.4 Mass-customisation, postponement and agility

Various views that have been formulated under the headings mass-customisation and postponement only address part of the supply chain problems arising from individualisation. Agility comes close to our concept of mass-inidividualisation.

10.4.1 The thoughts about customisation stem from the view that demand for variety in the market is substantially larger than can be supplied by existing industrial supply chains. This notion is common to all authors on this theme, and discussion concentrates on how (strategically and operationally) this heterogeneity in the market can be translated to strategy and configuration of these processes. It is in this debate that some similarities, as well as the most important differences between the separate approaches, become visible. In order to address both it is useful to summarise the approach to this topic being put forward in the number of recent publications.

Mass-Customisation

10.4.2 Although not the instigator of the discussion, it is B. Joseph Pine with his book ‘Mass Customization: The New Frontier in Business Composition’ (1993) who has raised international interest in the theme[iii]. More recently, in co-operation with James H. Gilmore (‘The Four Faces of Mass Customization’, 1997) he has further developed some thoughts with respect to the various ways of customisation. In their joint article, Gilmore and Pine explore cost-effective ways of tailoring products to individual client wishes, in four different versions (see Figure 10-1).

10.4.3 On the two axes (the product itself and the product presentation), they distinguish between adaptation to client wishes or not, the combination of which leads to four basic types of customisation: adaptive, cosmetic, transparent and collaborative.

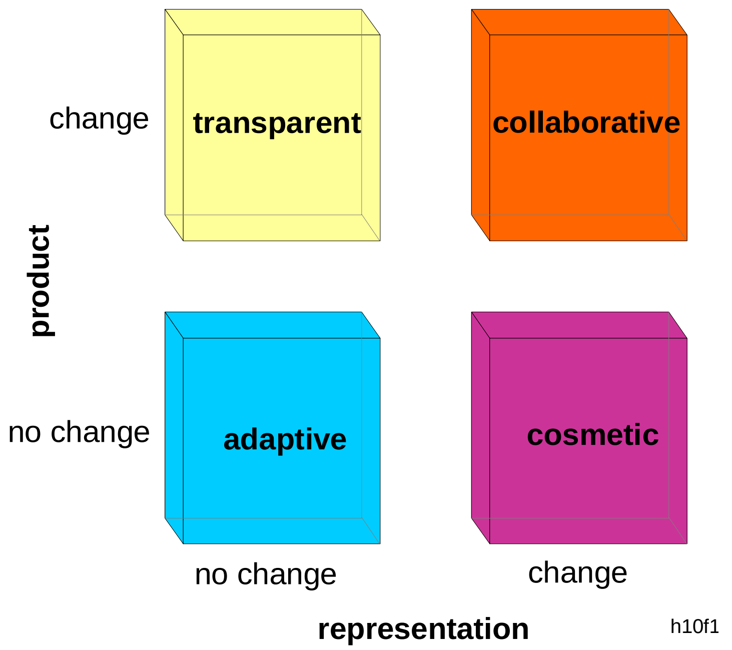

Figure 10-1 Four approaches to mass customisation (source: Gilmore and Pine, 1997)

- **Adaptive customisation**

10.4.4 Neither the product nor the presentation change in a client-specific way. This is a strange but essential variant of customisation, based on the adaptability of product functionality by the user (or influenced by the user). Just as pabx's (private telephone exchanges) are manufactured in a standard fashion and are programmed at the clients premises (which means that the function is brought in by software at the user end), we might start thinking of programming the buttons of a video recorder to client requirements at the moment of sale in the shop, rather than providing all possible functions in advance in a mass factory. Some companies are already experimenting with electronic music dispatch. This means that we can select the music we buy (on cassette, CD, etc.) out of a library; it will then be transmitted to us for home recording. Something similar has been introduced in the car industry by Jaguar. The customer, with the help of his dealer, can program all sorts of client-specific auxiliary functions at his end; Jaguar prefers this to standard-fitting the car in the factory, based on some sort of market segment requirement. In this way a giant box of modules is created in the production process, which enables clients to select and assemble them, not at the production end, but at the delivery end. Therefore, functional programming at the outlet level actually tailors the function towards the client's needs; it can be controlled by the client, without interference with the basic manufacturing process and the corresponding loss of cost parity.

10.4.5 Adaptive customisation is hardly new; maybe only the number of possible functions has increased substantially. When we consider television sets, this type of customisation has been available for generations in the form of programming channels and stations. The increased and better intelligence in user products turns this into a very powerful instrument for achieving individualisation without destroying the homogeneous mass characteristics of the supply chain. The consequences of individualisation, however, are passed on to the client, as many will notice when the channel distribution on the local cable net is changed.

- **Cosmetic customisation**

10.4.6 The product is not changed, only the presentation (packaging, promotion material, conditions and the product name) is adapted to the individual client. From the examples in the aforementioned article it appears that this mainly addresses customisation in the business-to-business interface. Here suppliers change the product presentation, based on differences in distribution channels, but essentially supply the same product. Many examples exist, ranging from retail brands in the food industry to laser printers and camcorders in the electronics industry. The presentation under this heading will hardly ever change for a single client or just a few clients.

- **Transparent customisation**

10.4.7 The product changes client specifically, but the presentation does not. In fact, because the presentation does not change, the client is often unaware that the product has been adjusted to his individual wishes. This mostly happens in cases where the client cannot (or does not want to) be bothered with the choice process. Examples quoted in the aforementioned article are hotels which retain the individual preferences of their clients to better serve them in the future, the chemical characteristics of the soap of Chemstation, and restaurants which know how to transform the main requests of their regular clients into menu suggestions. The supplier’s ability to obtain knowledge about their clients’ preferences, and his skill in translating them to an adequate composition of the product of service, is paramount in this form of customisation.

- **Collaborative customisation**

10.4.8 This is the individualisation of both product and presentation, what is generally meant with the word ‘customisation’. Tailoring a product to individual needs requires a dialogue with the client, who is often not a product expert, and therefore hardly able to express his wishes as a list of requirements to the supplier. The instrumentation of this dialogue (consider video systems which are used by hairdressers to present the effect of a different haircut, or similar systems which support the choice of spectacles) leads to individualisation of the presentation. Also, in the clothing industry (for example Levis personal pair), the choice of shoes, as well as proprietary delivery of (sports) bikes, presupposes a coherent change in the presentation and the product. In fact, the presentation process becomes a definition step in the product creation process.

10.4.9 The vision and examples used by Gilmore and Pine, are limited to inter-relation with the client, and the last (assembly) step in the supply chain process. Even examples which illustrate the influence the client has on product design, concern combinatorial possibilities in the final assembly. Therefore, examples are limited to the products and services for which the heterogeneity can be realised by new combinations of components.

Customising customisation

10.4.10 Lampel and Mintzberg ('Customizing Customization', 1996) distinguish the different forms of customisation in another way. Central in their approach is not the interaction with the client, but how the effects of customisation penetrated the supply chain. Starting with pure standardisation (industrial mass production), they then formulate a pallet of strategies, dependent on the depth of penetration and end with pure customisation (a fully client-specific supply chain process). See Figure 10-2.

10.4.11 Lampel and Mintzberg concentrate on the consequences for the supply chain, whereas Gilmore and Pine explore the way in which the client can express his individuality to the supplier. Both views can easily be combined. If we accept product presentation as part of the distribution process to the client, the four versions of Gilmore and Pine are variations on the last two steps of Lampel and Mintzberg's chain.

10.4.12 The difference is that (although it is not explicitly stated) Lampel and Mintzberg seem to support the idea that customising in assembly will always be combined with customisation and distribution. However, this point of view cannot be maintained e.g. in the case of the hamburger (which they mention themselves as being an example of customised standardisation), where 'customising' means a choice of mayonnaise, ketchup or mustard.

10.4.13 Many good examples of customisation limit the influence of the individual wish to the assembly, distribution and presentation aspects: industrially supplied kitchens on demand built from standard components, cars on demand and mobile telephones from Motorola are all excellent examples of such chains. Also Benetton's approach (colouring the finished product in the last stage of the supply chain process, instead of before the garments are processed) is a good example of the consequences of individuality being pushed in the direction of the market as far as possible.

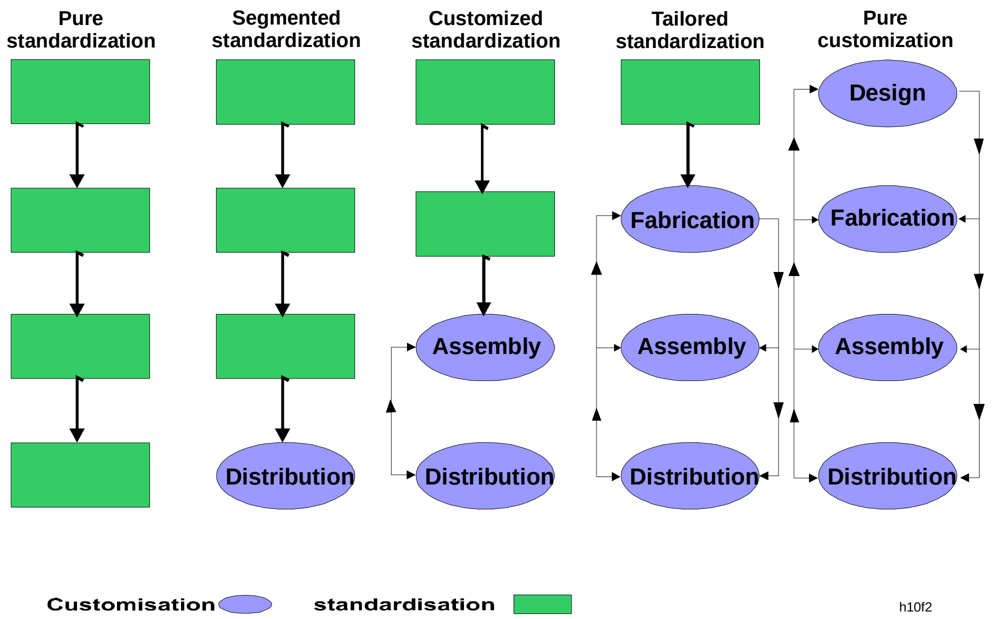

Figure 10-2: Customised customisation (source: Lampel and Mintzberg, 1996)

10.4.14 From our point of view, there are however a few problems with respect to Lampel and Mintzberg's reasoning. Firstly, as displayed in the examples, the mass character of the supply chains they mention decreases as customising progresses deeper into the chain. The Apollo project and the Olympic Games are used as illustrations of pure customisation. These are though one-offs, not mass production. Even the examples of complex industrial capital goods reflect more the character of one-time tailored manufacturing on a project basis than a regular production process. Implicitly the authors detach themselves from the ascension of mass customisation, as they move from mass to one-off, and with that they leave aside the cost parity question: how can we achieve individuality without extra cost?

10.4.15 Secondly, they provide their own limitations to individualisation within an industrial process configuration. From the Toyota (and thereafter the Nissan) example it appears that car manufacturers were finally facing extra costs which could not be converted into a price differential, when aimed at products with a maximum level of individualised choices. They found clients were just not interested in '87 different steering wheels'. Also, in the case of the insurers' branch, the willingness (and ability) of clients to study and understand an infinite variety of options appears to be very limited. The supplier simply cannot pass the problem of choice on to the client.

Postponement

10.4.16 Feitzinger and Lee (1997) elaborate on this view of structuring the supply chain for mass customisation:

> *"The key to mass-customising effectively is postponing the task of differentiating a product for a specific customer until the latest possible point in the supply network. [...]"*

In this view, three organisational design principles together form the basic building blocks of an effective mass-customisation program:

- A product should be designed in such a way that it consists of independent modules that can be assembled into different forms of the product easily and inexpensively;
- Manufacturing processes should be designed so that they, too, consist of independent modules that can be moved or rearranged easily to support different distribution-network designs;
- The supply network - the positioning of inventory and the location, number and structure of manufacturing and distribution facilities - should be designed to provide two capabilities: firstly, it must be able to supply the basic product to the facilities performing the customisation in a cost-effective manner; secondly, it must have the flexibility and the responsiveness to take individual customers' orders and deliver the finished, customised goods quickly.

10.4.17 In his article on customisation, Zeleny (1996) concludes that virtually all products can be customised. That includes products typically viewed as commodities, such as milk and dairy products. Zeleny:

> *"Consider the flavours: hours of runs of blueberry production, followed by the runs of strawberry, peach, and all other flavors. Then days of storing, refrigerating, promoting, stretching the 'shelf life', etc. Why not insert flavours at the point of consumption - letting the customer customise? This is called point-of-delivery customization."*

It could be interpreted as the ultimate level of postponement.

10.4.18 Postponement, however, is not always the right response. A good example of this is the Levi's personal pair (see Chapter 4.3). Made-to-measure has none or very little impact at the sewing atelier (the assembly stage of the process), but all the more at the cutting phase of the denim parts. Other examples of the complexity working far back into the supply chain, are cars with a variable wheelbase, and kitchens with non-standard measure. But also for supermarket individualisation works way back into the supply chain. Formulated in a different way, the less the penetration depth of individualisation in the supply chain process, the less the consequences are for the existing processes, and the easier individualisation can be achieved in an economic way.

10.4.19 Whereas Lampel and Mintzberg concentrate on the penetration of individualisation effects in the supply chain, the mass element decreases rapidly with deeper penetration. Increasingly, relevance is limited to a project-based, one-to-one relationship in the pure customisation form; no specialities without extra cost. Gilmore and Pine do orient themselves to the mass dimension of customisation, but they limit the variations in products and presentation to those products and services of which the total variety can be achieved in the end (with assembly, distribution and/or presentation). In other words, they deal only with those products which demand only modularity on the component level; in situations where this modularity is not sufficient, but modularity on the process level is required, their vision does not offer any help on how to do this without extra cost.

10.4.20 By limiting the reasoning to the last change of the supply chain (Gilmore and Pine), or by accepting that customisation leads to a loss of economy of scale (Lampel and Mintzberg), the core issue is avoided. Central to this debate is not the question whether the market is individualising, but how this need can be served without prohibitive extra cost. These same problems, although from a different starting point, form both the core of the 'agility' and 'mass-individualisation' approaches: the achievement of individualisation without extra cost throughout the whole chain, from design to use, for consumer products as well as in business-to-business relations.

Agility and mass-inidivdualisation

10.4.21 An industrial process set-up, characterised by central, planned and prediction-based control and the utilisation of batched homogeneity to achieve economies of scale, is fundamentally inadequate to provide specials without extra cost. It is this notion which has formed the basis of thoughts under the heading 'mass-individualisation' and 'agility'.

10.4.22 Mass-individualisation is the concept, which emerged in the Netherlands out of creating the long-term strategic orientation of the Albert Heijn retail chain. Agility has come about through the work of the American Iacocia Institute to increase responsiveness to change and unpredictability in American industry. While the Dutch initiative focuses primarily on chains for consumer products, the Iacocia

Institute derives most of its examples from the business-to-business market. In both cases, however, attention is firmly focused on the far-reaching consequences (elegantly avoided in the aforementioned articles about customisation), for the configuration of business processes.

10.4.23 Goldman, Nagel and Preiss in their book 'Agile Competitors and Virtual Organizations' (1995) define agility *as "the capability of operating profitably in a competitive environment of continually and unpredictably changing customer opportunities".* This departs from the view that the continuous refinement in change of prediction methods will not provide adequate control of processes for the future. If prediction no longer works, the emphasis of all business processes will be put on responsiveness. When all possible clients requirements can be accommodated instantaneously, nothing needs to be predicted anymore. The authors consider through-put time (from concept to cash) as the dominant process quality parameter. Just like Gilmore and Pine in their examples of collaborative customisation, they consider joint design with the client of essential importance, but do not limit design to recombination of product and service components.

10.4.24 Kidd (1994), author of the book 'Agile manufacturing, forging new frontiers', formulates it this way:

> *"Manufacturing industry may well be on the verge of a major paradigm shift. This shift is likely to take us away from mass production, way beyond lean manufacturing, into a world of Agile Manufacturing".*

The concept of agile manufacturing builds on developing agile properties, and using these to create competitive advantages. Among these properties are:

- Rapid responding to changes in customer demand and in the market environment in general;
- Being able to use and exploit knowledge as a fundamental resource, e.g. by using technologies to leverage people's skills and knowledge;
- Making use of virtual corporations: *"the synthesis of a number of enterprises that each have some core skills or competencies which they bring into a joint venture operation, which is based on using each partner's facilities and resources";*
- Being able to take advantage of 'windows of opportunities' that appear in the marketplace;
- New ways of interacting with customers, giving them access not only to the products and services, but also to the competencies, *"[...] so enabling them to use these competencies to achieve the things that they are seeking";*
- Deployment of advanced information technologies, e.g. linking computers across applications, across functions and across enterprises (CIM);
- Development of nimble organisation structures.

10.4.25 Brennan (1994) adds to this that:

> *"Agile manufacturing is aimed at enabling the production of more highly customised products, when and where the customer wants them. Thus, economies of scope, involving the servicing of ever smaller niche markets even to the level of single customer orders without the high costs traditionally associated with customised production, represents one of the key themes of the agile manufacturing paradigm."*

He introduces the concept of 'Instantaneous Engineering', a means of enabling customer-driven manufacturing and a realisation of agile manufacturing. With instantaneous engineering, the customer can switch from the current situation of choosing a product among the existing ones in the market, to the luxury of actively participating in product design, engineering, fabrication and delivery in an immediate manner, by using a manufacturer-customer computer network.

10.4.26 Although the perspective of the agility thinkers has arisen not from individualisation, but from the need to deal with unpredictability, in practice both approaches are very close. Moment-specific individuality of consumer behaviour is one of the most important causes of unpredictability, and brings about the necessity of creating ultra-fast responsiveness.

Mass-Individualisation

10.4.27 Now we have arrived at the effects of individualisation in the fast moving consumer market. The core question which has emerged here, at Albert Heijn amongst others, is how to accommodate increasing individuality in client needs by continuous improvement of service quality and specificity, without incurring the costs and inconveniences which would result from the current process configuration. Ever expanding choice leads not just to more cost, but also to loss of accessibility (and with that service quality) for the consumer. In achieving both cost targets and reliable and consistent quality, the exponentially increasing complexity of these business processes, based on industrial paradigms, play a central role (Van Asseldonk,1995, 1996, 1997; TVA, 1995). As a conclusion of this reasoning the accommodation of individualised demand in a mass market at no extra cost implies:

- changing the orientation of chain control (from push to pull);
- direct interaction between client and chain process (Point of Sale);
- planning-less, interactively coupled supply chains;
- advanced interface-less information logistics;
- management-extensive network organisations;
- networks of strategic alliances between chain players.

A summary of the relationship between the various views is indicated in Figure 10-3.

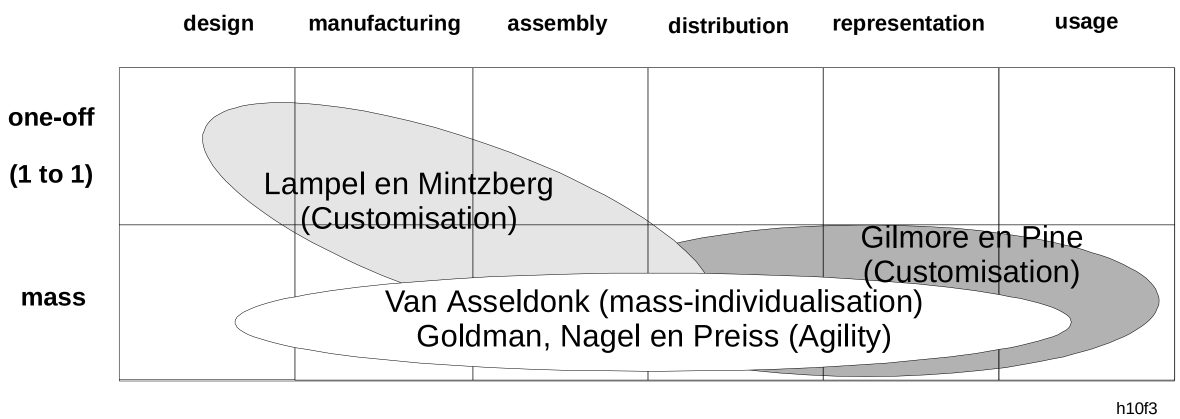

Figure 10-3: Different views on individualisation in supply chain processes

10.4.28 Whereas Lampel & Mintzberg concentrate on the penetration of individualisation effects in the supply chain, the mass element decreases rapidly with deeper penetration Increasingly, relevance is limited to a project based, one-to-one relationship in the pure customisation form; no specialities without extra cost, but specialities at extra cost. Gilmore & Pine do orient themselves to the mass dimension of customisation, but on the other hand, limit the variations in products and presentation to those products and services of which the total variety can be achieved in the end, i.e. assembly, distribution and/or presentation. In other words, for those products for which modularity on the process level is required, their vision does not offer any help.

10.4.29 These questions, although from a different starting point, form the core of both the 'agility' and 'mass individualisation' approaches: The achievement of individualisation without extra cost throughout the whole chain, from design to use, for consumer products as well as in business to business relations.

10.5 The nature of customisation

Dependent on the nature of customisation three basically different forms can be distinguished:

- **Customisation above the level of the product composition;**
- **Customisation at the level of product composition;**
- **Customisation below the level of product composition.**

Downstream from the Customer Decision Point (CDP) supply chains need to be configured as responsive, event-driven sequences of activities. Two principal problems have to be resolved (dependent on the category mentioned above):

- **The creation of re-configurable process step nodes atoms;**
- **Interactively self-organising chains of process nodes.**

10.5.1 The desire to achieve a much deeper penetration of mass-individualisation into the chain, requires modularity at the process level. The supply chain must be broken down into re-combinable chunks, 'atoms'. (Compare the concept of the fractal supply chain, Warnecke 1993) The word 'atomisation' is particularly relevant in this respect, as an atom is the smallest chemical particle containing specific material properties. The specific chemical identity disappears when an atom is broken down into electrons, protons and neutrons. Subsequently, by connecting atoms in various process steps, an almost infinite variety can be achieved. This gives rise to the question: where does the energy come from to create meaningful order in the sequence of atoms, in a purposeful way, throughout the supply chain? At present, this order is mostly forced from a central control point.

10.5.2 In supply chains, networked characteristics become when the normal flow of goods is disrupted. 'Improvised' re-routing as a result of e.g. water floods, ad-hoc fault repair when deliveries fail are both examples of the resolving of unexpected situations by networked systems, as there is no time to create a new structured answer. In many crisis's the crisis team is the core of the networked structure, addressing the origins and resolution of the crisis.

10.5.3 Figure 10-4 summarises the consequences for customisation, with regard to the necessity to create fractal supply chain nodes, as well as an interactive self-organising way, for linking these nodes together. The reason for those changes is predominantly tied to the way in which customisation, in specific circumstances, can be achieved.

		fractal supply chain nodes	**interactive self-organisation**
customisation	**above product composition**	not necessary	not necessary
customisation	**at product composition**	in assembly	not necessary in simple assem-bly operations
customisation	**below product composition**	downstream from CDP	necessary

h10f4

Figure 10-4 Customisation, fractal structure and interactiveness

10.5.4 The first is the ability to achieve customisation above the product composition level, meaning that the product itself need not be changed. In Gilmore and Pine's terminology, this is equivalent to either adaptive or cosmetic customisation, i.e. merely a change in representation, not in the product itself. In the Lampel and Mintzberg model this type of customisation would involve only the distribution step. The whole supply chain can remain as it is. Fractal (atomised) supply chain nodes do not have to be identified, nor does the way the interaction between those nodes takes place have to be changed from the planning and control system which characterises most industrial systems.

10.5.5 The second is in the form of tailoring, that can be achieved by changing the product composition by means of modularising product design. In this way it provides an enormous variety of differently composed products, based on a relatively limited number of modules. This involves largely what Gilmore and Pine mean by either transparent or collaborative customisation, i.e. a change in the composition of the product. In Lampel and Mintzberg's model this involves customising the assembly step. The need to identify fractal supply chain nodes only covers the assembly processes, which in many cases are placed at one specific geographical location. Within the assembly operations such supply chain nodes need to be identified, because they will be physically close together and limited in number. In principle, however, the complexity of configuration will often still be within the perimeter of what can be achieved by a traditional, procedural, top-down system. Hence, there is a point beyond which the processes can no longer be maintained in the standard mass-industrial way.

For example in the car industry, the production of doors can be fully standardised. They only get specific destination when they are painted in a specific colour, supplied with or without electric windows, etc. Many of these variations can be implemented at final assembly. In other words, under these conditions postponement will be a sensible strategy. If assembly operations become more complex and the number of permutations increase, it might be necessary to introduce, at least partly, self-organising, interactive principles in these assembly operations.

10.5.6 The third requires customisation below the level of product composition and therefore at the process level. Customisation below the level of product composition' is not identical to 'pure customisation' as understood by Lampel and Mintzberg. As stated in par. 10.4, in the examples Lampel and Mintzberg provide, they in fact reduce this pure customisation to 'one-off' projects. This is contrary to our aims. In supply chains in which customisation takes place below the product composition level self-organising, interactive principles have to be applied. At that point individualisation works through many steps in the supply chain process, and linking them up in a meaningful and efficient way is very soon beyond what can be achieved by a top-down planning and prediction system, both economically and in terms of complexity.

10.6 Atomic supply chain structures

By breaking down the industrial chain into the smallest meaningful functional process steps, a limited variety of such functional steps can produce extreme amounts of output variety, provided they are fully compatible.

10.6.1 The simplest way to try to achieve more variety in the industrial phase of the evolution was to switch complete production lines from one product to another. These early attempts resulted in enormous cost and time losses as production chains were reprogrammed and refurbished to start building another product. Many attempts have been made to reduce the down time of a supply chain when a switch was made from one product to another. At the moment, technology enables fast-switching manufacturing lines which can switch on-line between one product and another (see Figure 10-5).

10.6.2 The production line can still only make products in batch mode and can only make series of products of a certain type, or individualised products at considerable cost. It is primarily the production planning that creates these enormous costs of complexity. Stannack (1997) provides the example of Deere's plant in Moline, Illinois:

> *"[...] the variety of customised planting equipment being assembled - 1.6 million possible unique models in all - made generating an optimal production plan beyond the capacity of any traditional expert system, let alone human. In the past, untold hours were eaten up in shuffling data to hammer out weekly manufacturing schedules that rarely came close to the production targets[iv]."*

10.6.3 We however do not want flexibility, but responsiveness. Not multiple batches, but flow. Flow means that we can actually switch every combination for every single product. Infinite variety requires infinite connection possibilities between the building blocks. If we cannot connect one step to another, the process stops and will not produce the output. Infinite variety also means that we can follow the case throughout the production chain. In companies such as Federal Express this concept has already been well developed. Given the infinite variety of paths the parcel might have to take to get from sender to consignee, the company needs to know exactly where the parcel is at any moment. If it loses track, it will never find it again, and it will not be able to give the client any information on where the package is and where the procedure might have gone wrong.

10.6.4 Network supply chains, therefore, consist of basic, atomised functions. Any path through these functions is a different sequence of supply activities. Some of the activities might be required all the time, and some of them only incidentally (see Figure 10-5). In a simple network like this, with 17 nodes and 5 steps, there are 742560 different ways (assuming no duplication of steps) of manufacturing things (see also Warnecke, Fractal supply chains, 1993). Only in this way can we keep both simple structures and infinite variety[v].

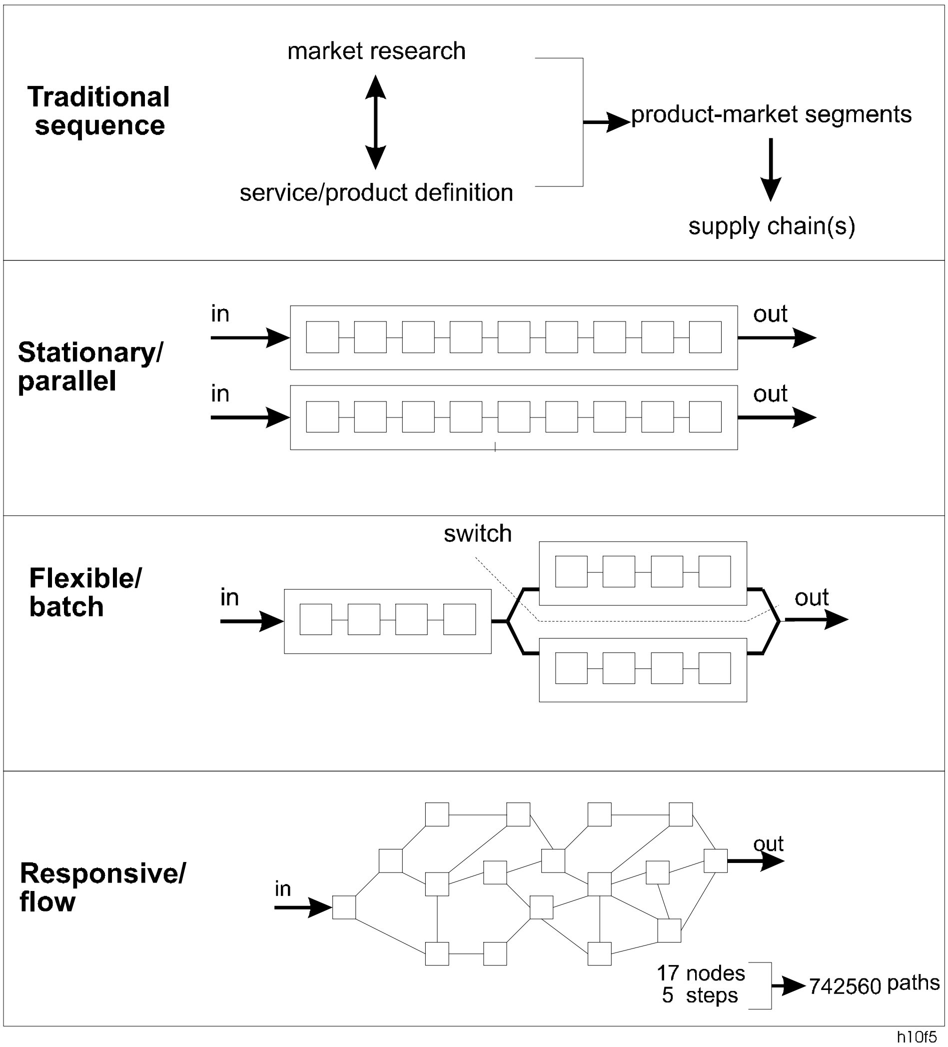

Figure 10-5: From production sequence to flow system

10.6.5 Pine, Victor and Boynton (1993) support this point. While lean production and continuous improvement strategies focus on tightening the links between the supply processes, mass-customisation requires a dynamic network of relatively autonomous operating units. I.e., each module of a supply chain is typically a specific process or task. These modules, which may include outside parties (suppliers, vendors), typically do not interact or come together in the same sequence every time. Rather, the combination of how and when they interact to make a product or provide a service, is constantly changing in response to what each customer wants and needs. Management's task is primarily to facilitate this coming together and linking of the process modules. *"The key to success"*, the authors state, *"is designing a linkage system that can bring together whatever modules are necessary - instantly, costlessly, seamlessly, and frictionlessly."*

10.6.6 In practice, to achieve mass individualisation, managers first need to turn their processes into modules. Secondly, they need to create an architecture for linking them. The co-ordination of the overall dynamic network is often centralised (!), while each module retains operational authority for its particular process. Compensation for each module is based on the uniqueness and value of the contribution it makes towards manufacturing the product. In a mass-individualised context, however, central co-ordination of the production network will not be possible, for it will lead to a burden of co-ordination costs. Therefore, the network needs to become self-organising. The only solution to combine high levels of heterogeneity with industrial cost-parity is to atomise the supply-chain process into recombinant nodes, and make these nodes self-organising, driven by the client requirements.

10.6.7 In a number of examples we can think of highly-tailored supply chains which exist already or might be created in the future. If we look at a city as one giant supply chain of independent shops, a large amount of self-organisation is taking place already. We do not recognise it as one production system, yet nowadays we are beginning to market cities as an entity. This manufacturing process is largely self-organising. There is no central authority who organises it. Some cities seem to be very successful in doing that, others are not.

10.6.8 The next example is one which some people may find it very strange to regard as a supply chain; we mean a professional service such as education. We know that students have different needs and different ways of picking up information and knowledge. Yet, we design a middle of the road, pre-programmed educational system which with much effort produces standard output and many drop-outs. We might conceive of educational modules which chain up to create a completely educational package, much more suited to the individuality and background of the student, thereby creating an adaptive supply chain.

10.6.9 Another example takes us into the world of the insurance industry. It is easier to create an adaptive supply chain in this industry, since in a sense the product is information. It is already possible to get tailor-made quotations for mortgages and life insurance, designed for our specific needs, which are verified and authorised at the very moment we are sitting at the computer screen. It is highly modularised inside and it is built in such a way as to bring together all sorts of different modules in the total package, on-line in real time.

10.6.10 Virtual, electronic shopping is still very cumbersome and is oriented very strongly to functionality, not to the emotions. However, we can see the different functions come together. At Internet, for example, we can chain together virtually any supply chain for any combination of products that we desire. However, as has been argued in Chapters 5.11 and 7.7. we do not necessarily aim for maximum connectivity in the fractal structure. There is a close relation between the complexity of the solution landscape (as governed by the N/K connectivity) at the supplier's side and the complexity of that landscape at the customer's side. When these solution landscapes differ substantially, this leads to an increase of the effort or cost needed to sustain the interaction. This would be the case with an industrial supply system confronted with heterogeneous and unpredictable markets, but also with a system capable of providing infinite variety in which customers cannot find their way. In the first case, it will cause complexity cost at the supplier's side; in the second case, it will cause search cost at the customer's side.

10.6.11 The same argument would apply for the connectivity between different internal processes at both the customer's and the supplier's side. When the N/K solution landscape of one process differs substantially from those of other processes, an imbalance occurs, requiring an increase in effort and cost to sustain the connectivity. This connectivity, both within and between organisations and (inter-organisational) entities, is governed to a large extent by the way information is exchanged between these entities, as will be dealt with in Chapter 11.

Example

Retail supply chain

One of the most impressive movements towards the kind of supply chain of which we have been talking, is the transformation which is taking place in the supply chain of the retailer that was used as an example in the previous chapter. In the old set-up the supply chain could deliver goods to the shops anywhere between 3 days and 26. It had 26 different streams, each with its own dedicated ordering and planning system. The whole system, in terms of its top-down planning, was based on the assumption that trucks had to drive around fully-loaded.

This system produced an efficiency which can be most easily explained by saying that there were just as many trucks as there were shops. It is quite conceivable that if every shop would have had its own truck, it could have brought the goods into its shop on its own, having truck and crew available all week. This system was clearly not good enough, because it was not responsive to the dynamics of the business, which are mostly on a daily schedule. Thus, the assumption made at the outset was that every order had to be delivered to the shop within 24 hours. In order to be safe, the time goal was set at 18 hours. So whatever a shop ordered, within 18 hours it was delivered. Given the buffers in the racks in the shops, it would prevent giving no for an answer to clients.

In the new set-up the number of streams has been reduced from 26 to 2. The two streams reflect the division between transport of cooled products and non-cooled transport. The ideal is to bring even those together, but that would mean surmounting technological problems.

As for the performance improvement, the through-put time was a standard 3 days, but some products actually remained in the chain for 26 weeks. This period is now reduced to 18 hours, varying from just over 20 hours to 2 hours. The gain in efficiency compared with a highly-optimised, traditional, logistical planning can potentially be about 25%. The total stock contained in a supply chain, which was originally measured in days, is now measured in hours.

In implementing this change, however, it proves to be difficult to achieve 25% because of non-linear transmission of disturbances. All buffers are taken out and therefore small causes create avalanche effects in the supply chain. At the moment, the retailer is maintaining sufficient air in the system to damp the effects of transmission of errors through the system. This is done in the same way that barriers are placed on a mountainside to prevent avalanches from becoming too forceful.

10.7 Networked supply chains

Supply chains have to become networks of self-organising nodes, the process itself being a path through a sequence of (alternative) nodes. The moment-specific organisation of the nodes into chains is not provided by central planning, but rather by local intelligence and "intelligent" goods. This way complexity becomes embedded in the process (through interactive rules), instead of being built around the process. Simple, recursive IF/THEN rules, to be applied by the nodes, can provide elegant solutions to extremely complex problems.

10.7.1 As Kelly (1994) points out, technological systems like modern organisations achieve complexity by creating multiple layers of simplicity.

> *"The only way to make a complex system that works, is to begin with a simple system that works (...) Complexity is then created by assembling it incrementally from simple modules that can operate independently."*

10.7.2 Let us turn again to the cross-road/roundabout example: the difference between a cross-road and a roundabout is the way in which processes are controlled. In the cross-road example we add ever more control complexity in an attempt to adapt a basically unfit process to the complication of the heterogeneity and unpredictability. We build, as it were, the complexity around the process. In the roundabout example, the complexity is caught in the process itself. Because of the continuous interactivity, the total complexity of the process is built from a collection of simple interactive small processes. In other words, complexity is conceived as 'recursive simplicity'. This is the key to a breakthrough of complexity as a consequence of heterogeneity and unpredictability in business processes. Just as the complex structure of an ant colony finds its origin in infinite repetition of a few simple interactive rules, business processes can perform very complex tasks while being built up from coupled simple processes.

10.7.3 Attractive and appealing as the example of the roundabout may be as a metaphor for organising supply chain processes, only a few examples exist as yet when it comes to applying such principles to real supply chain processes. However, a number of (admittedly still very simple) examples can be mentioned. The first one is the New York taxi system. In the old days the taxi centre despatched requests for transport to specific drivers, based on the proximity of a specific taxi driver to the pick-up point, and in addition, rules of fairness. Regularly, however, mistakes were made if a taxi was not where it was supposed to be, or if taxi drivers were, for whatever reason, not interested in the job. As a consequence, the client would call again, complaining no taxi had shown up. At some stage, the despatching system was changed. Rather than despatching jobs as an order, available jobs are now broadcast on a taxi radio network, and taxi drivers respond voluntarily to these requests. The result was very interesting. The new system raised the quality of service provision, as taxi drivers volunteering for the job will normally do the pick-up. Moreover, the broadcast information would tell taxi drivers cruising in a quiet area, in what part of the city there would probably be clients. As a consequence, the fleet of taxis would, without any prior planning and control, move almost automatically with the density of jobs available.

10.7.4 Another strikingly simple example is the problem that was described in one of the Dutch newspapers some months ago. Readers were given a puzzle about a newspaper delivery problem that was situated in New York City, and were asked to come up with solutions. The question was to find the best route from the despatching point, servicing all newspaper subscribers (in this case there were 80), who were randomly distributed over the rectangle of streets of New York City. In fact, readers had to identify three routes and sum these up; the winner would be the reader who would arrive at the shortest route (provided he would include the route descriptions as well). This problem resembles the well-known travelling salesman problem, in which one has to find the shortest route for a sales man along a number of stops on a commercial trip. Mathematicians have proven that above a certain level of points there is no analytical solution for this problem. Simply trying all possibilities is inconceivable, as 80! stop points mean 80 possibilities. Even with the use of fast computers it would take forever to find out the best route.

10.7.5 The puzzle interested us to find out whether this kind of complex supply chain question could be resolved by simple recursive rules[vi]. In the end we came up with the following solution: starting at the despatch point we randomly pick a first delivery point and draw a line between the despatch point and that delivery point. Subsequently, we pick the second delivery point randomly and consider whether it would be logical to add this point in between the despatch point and the first delivery point, or to put it at the end of the stretch. Then we pick a random third point and consider whether it would be advantageous to put it between the despatch point and the first point, between the first and the second point, or after the second point. We then keep applying this rule until all 80 stops are catered for.

10.7.6 The results were striking. Not only will every solution be remarkably close to the shortest route (in round figures: about any solution generated this way will have a length below 6,000 length units, whereas the theoretical minimum solution is 4,000 length units and the theoretical maximum solution will be roughly 400,000). By memorising the best solution so far, normally solutions below 5,000 length units will be found within ten tries. If a computer is used, the algorithm works very fast. Ten runs can easily be made in a matter of seconds.

10.7.7 This is not just an excellent example of how recursive simplicity can attack complex supply chain problems, it also tells something different. Imagine a newspaper boy who is taking over the newspaper route from a friend. He will probably walk the route with his friend once; the next day he will follow the route as given. But what if new subscribers must be inserted? He will consider where they would be best put in the existing route. Indeed, just as the algorithm works, as described before. Seen from this point of view, the algorithm only mimics the natural evolution a newspaper boy would follow in the course of the development of his route and adaptation to changing circumstances. This might be quite different from the way in which a professional route planner at the newspaper headquarters would define the routes. He would most probably adopt an engineering approach, trying to find mathematical or planning rules which enable him to design the best route along the known points. But, like we said before, mathematicians have proved that this problem cannot be solved in an analytical way if a certain number of points is exceeded.

10.7.8 From a perspective of self-organising supply chain structures, the discussion on the future of computing is also of interest. Whereas the PC (Microsoft-Intel) approach offers us ever larger software packages containing all functionality we might possibly want, requiring (as Oracle's chairman stated*) "1.5 million lines of code to print an address on an envelope",* web computing starts from a completely different concept (see also Chapter 9.7.9). It makes available software building blocks as required by the user, and installs these entities as 'nodes' in the client's 'supply chain' (the program). Hence, driven by client requirements his software will self-organise, as it were, and configure the combination of subsequent functional nodes required. It will adapt and modify itself to the client requirements, beyond the range of currently installed functionality. In other words, while Microsoft tries to cope with unpredictable requirements by creating a huge ‘stock’ of all functions the user could possibly want, web computing shows all the signs of self-organising re-configurability. One could argue that stocking software functions is not expensive, but the investments required in computer power, memory capacity installation and commissioning, maintenance of applications, staff training and problem solving, accumulate in many companies to costs that will exceed the price of the software itself.

10.7.9 As telecommunication systems have become more extensive and global in character, and have been stretched to carry data and images besides conventional voice signals, their carrying capacity has come under severe pressure. The major problem in such networks is to allocate network capacity dynamically to any particular pathway or route, through the nodes of the network. Traditionally, this has been done by repeating the following procedure:

- Each node in the network collects global network information from all other nodes;
- Each node then computes the optimal routes through the network for all destinations from that node;
- Each node then updates the routing scheme.

10.7.10 This conventional scheme breaks down as the volume of traffic increases, because the assumption that the network remains static while the nodes are collecting the relevant information, is violated. A solution to this problem involves treating network nodes as intelligent entities that make their own optimal routing decisions. This also involves a continuous three-step procedure, albeit much simpler and with much less information transmission:

- Each node seeks information from all adjacent nodes, that advise whether they wish to transmit a packet of data to that node;
- The node then computes its future state from this information and decides whether or not it can receive such packets;
- The node then informs adjacent nodes whether or not they can transmit a packet.

10.7.11 Nodes act at one time as ‘input nodes’ and at other times as ‘output nodes’. Each node is autonomous, being able to independently collect and process information, thereby reducing the total data load on the network. Instead of nodes being forced to accept packets of data in transmission, regardless whether they can cope with them or not (the latter leading to a network breakdown), the holonic scheme allows for intelligent operation, in that nodes independently and autonomously make their own assessments as to whether or not they can accept a packet. However, they are not free in rejecting packets that they can indeed accept; system integrity calls for their accommodation to the overall needs of the system. These conditions ensure the network’s capacity to adjust intelligently to different operating conditions; they make it possible to easily extend or contract the network through addition or deletion of operating nodes. Also, the reliability is enhanced, because breakdown or overload of individual nodes will not cause the whole network to collapse.

10.8 Zero throughput time

The key overall process performance parameter is the ratio between the sum of the processing times over the nodes divided by the total through-put time from buying event to delivery (e.g. for cars: 3-4 days/3 months).

10.8.1 As argued in Chapter 7.4, two antagonistic performance dimensions govern the learning process in self-organising chains of nodes. One reflects the client's interest (a measure of the performance of the process concerned), the other the supplier's interest (a measure of the cost/sacrifice caused by the process). Getting information on ever better combinations between the two dimensions is the driving force behind the evolution of the process. In other words, it is not the best compromise that leads towards a better combination, but rather continuous small steps.

10.8.2 Performance in supply chain systems, the overall quality parameter, is the ratio between overall processing and delivery times, very much along the line of the agility thinkers. As we aspire to create self-organising supply chains, delays at the chain level are a result of either of the following:

- Imperfect connectivity between the nodes;
- Planning and control processes which require time to provide new instructions;
- Capacity showing lack of parallelism;
- Batched nature of the process steps.

10.8.3 All these delays reflect the structural limitations of our industrial mass-production structure, and if we strive towards zero delivery time, all will need to be eliminated from the supply chain. Hence, through-put time is an excellent and universal parameter to measure the self-organising properties of the chain

10.8.4 With respect to the aspect of zero lead time, many of the current attempts are geared towards speeding up through-put in the process, thereby creating multiple batch situations instead of a continuous flow. Collecting smaller quantities of the product to be manufactured or supplied within processes. Zero lead time, however, means no overall planning and scheduling, and at this moment we cannot conceive logistics and manufacturing systems which can do without.

10.8.5 If we want zero lead time, the supply chain must be without interfaces and without stages in which products are stacked, waiting to be moved to the next stage. The process must be 'interface-less', both at the physical end of the supply chain and at its information end. Because if we can provide the goods but are unable to process the information at the same time, we might find ourselves in the same situation as the Dutch PTT Telecom after its privatisation: the company can provide the service too fast for the surrounding bureaucracy to follow.

10.8.6 In other words, the total processing time has to equal the lead time. Again, we give an example from the car industry. It may easily take three to four months for a new car to be delivered, while the total processing time will probably not exceed two weeks. During the rest of the time, the products or part of the products are waiting somewhere, taking the process further away from zero lead time. In the future clients might not accept this waiting time any longer.

10.8.7 The supply process also needs output-driven performance. If overall planning and scheduling are out of the question, some sort of master system must take control over what will happen. If it is going to be a sequence of events, the output of one event will be the input of the next one. If agents are not governed by creating that output, they will not match the input requirement of the next stage of the process. An output-driven performance requires qualitative on-line, real-time process monitoring. Most of what we monitor are quantitative data rather than qualitative. In many cases we do not even know how to express qualitative performance.

10.8.8 Zeleny (1996) states that traditional concepts of continuous improvement and total quality management are simply not enough for mass-customisation:

> *"One cannot continually improve mass production, command hierarchy and statistical forecasting, while hoping to stumble into mass customisation. [...] The traditional forecasting is also losing its role in mass customization. Producers do not have to forecast market demand if they produce only what has already been purchased. Forecasting (like inventory management and buffer hedging) is necessary only in the mass production, i.e., when producing standard and other ill-fitting sizes or configurations for the warehouse or shelf, ahead of the purchase, in a 'just-in-case' fashion. All mass producers remain obsessed with market forecasts."*

10.9 Propagation of disturbances

Like all dynamic interactive systems, event-driven supply chains are susceptible to apparent chaotic behaviour, as a result of non-linear propagation of disturbances combined with the effects of human decision making.

10.9.1 Effects of non-linear propagation of disturbances have been known for a long time in industrial dynamics. They are generally referred to as Forrester effects, as they were extensively described by Forrester in the 1960s.

10.9.2 This problem does not only occur, however, in the classic industrial supply systems which rely largely on buffers of inventory. It also emerges in atomised, self-organising chains.

10.9.3 By looking at an atomised supply chain process from an interactive dynamic point of view, many of these processes can be simplified radically. Not, as in the roundabout example, by simplifying the business, but by accommodating the market-driven business complexity by processes that are interactively coupled, although they themselves are essentially simple. However, interactive (read non-linear) dynamic processes very easily become unstable. They are very sensitive to small disturbances, which means that these can lead to large consequences. Also this is easily perceived in everyday traffic, if we just observe the small causes which create large traffic jams on motorways. The control of this instability over the total chain is not a trivial question, it is an issue about which relatively little knowledge is available in a corporate environment.

10.9.4 The occurrence of dynamic instabilities in long interactive supply is illustrated in the work of Sterman c.s. as conducted at MIT on computer simulations of beer supply chains (see Sterman, 1989; Mosekilde, Larsen and Sterman, 1991). The behaviour of such chains closely resembles the appearance of instability known from non-linear dynamic systems (chaotic systems). Small disturbances in the demand can lead to closing down and restarting whole factories upstream.

10.9.5 In the 1960s at the Sloan School of Management the ‘beer game’ was developed, to illustrate industrial dynamics. This concerns a four-stage beer distribution system, consisting of the brewery, the distributor, the wholesaler, and the retailer. Between these stages, inventories are present to dampen required adjustments in production. The objective for the individual participant is to minimise cumulative costs during the game, assuming that both holding inventory and out-of-stock conditions cost money. The game has been played a lot by management students at Sloan and at MIT and by experienced managers from US companies.

10.9.6 Mosekilde, Larsen and Sterman (1991) measured players’ performance from 48 games over a period of four years. The performance of all players turned out to be systematically sub-optimal. Because of the built-in delays and non-linear constraints many players proved unable to achieve a stable system operation. Consequently, large-scale fluctuations developed. It turned out that marginal changes in final demand or in ordering policy at one of the stages could completely change the system behaviour. When such changes have occurred, the system moves in a highly irregular and unpredictable manner until, after a randomly distributed time period, it suddenly latches onto a stable situation.

10.9.7 When controlled by humans, average costs turned out to be 10 times as much as the minimum costs produced by a computer simulation, which used a fixed decision rule for orders. Though the beer distribution chain is extremely simple compared to most other management systems, it is apparently complex enough to prevent participants from discovering a policy that is even close to optimal. In contrast, the computer simulation, after some experimenting with the decision rules, is able to show controlled behaviour, as displayed on the right side of Figure 10-6. Here the factory inventory and the distribution inventory, which are just two system parameters, are plotted against each other in time. The result looks remarkably like a two-dimensional version of the Lorenz attractor curves. It seems to be going around in loops all the time and never explodes. Apparently there is an attractor somewhere which keeps the imbalances between limits, but the system never improves. Even the computer simulation cannot stabilise the system, but creates system dynamics instead.

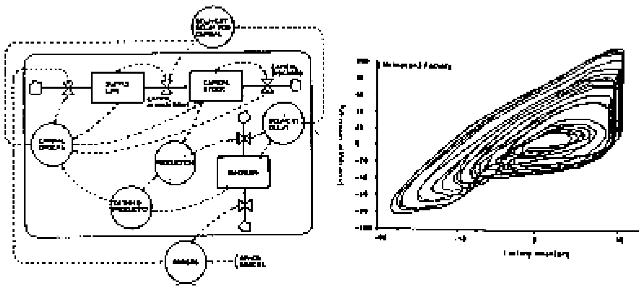

Figure 10-6: Sterman’s beer chain

10.9.8 This indicates that in managing and controlling business processes phenomena alike complex, dynamic behaviour, do occur. Sterman’s objective actually was to get away from this. Yet, if we move to a world of mass-individualisation, we may not be able to do so. We will hence have to understand how these mechanisms work, in order to cope with their effects on our business. In other words, this susceptibility may prove an inherent problem that governs supply chains, especially when these chains are controlled by human interaction.

10.9.9 One solution for reaching this is to devise fixed links between the nodes, thereby in fact converting them into a 'train'. This would however place a burden on chain flexibility and re-configurability. Besides, it would again import central control and co-ordination, which are unfit to deal with infinite heterogeneity and unpredictability in demand. Richardson (1996) argues in this direction, while investigating the advantages of vertical integration in a highly competitive and volatile environment such as fashion apparel. He starts his argument by stating that for quick response it is necessary to have modern information technologies (CAD/CAM, EDI, POS, etc.), supply chain co-ordination (working relationships, information sharing, etc.) and risk-sharing along the supply chain.

10.9.10 Richardson continues:

> *"Vertical integration is not generally considered to be a superior form of organizing in volatile environments. [...] The consensus seems to be that firms in volatile competitive environments should focus on their core competence (cf. Hamel and Prahalad) and look for ways to apply it in more or less temporary arrangements with other firms."*

He states, however, that vertical integration also has some potential benefits in this kind of environment:

- It may provide product differentiation advantages that are difficult to imitate;
- It may provide superior market intelligence;
- It may provide superior operational flexibility (while at the same time, however, it may constrain structural or strategic flexibility);
- It may speed up the learning process with regard to customer satisfaction, enabling the firm to identify mistakes more quickly;
- It may provide the necessary control to take corrective action rapidly.

10.9.11 The last item is considered very important: the firm needs sufficient control over the assets and capabilities in the value chain to effectively co-ordinate its activities and achieve its goals. Richardson:

> *"Through greater control of the retail operation, the integrated apparel makers can better manage the creation of short term advantages. The most forward integrated firms can quickly change their product offerings, both to respond to changing fashion trends and to create new ones."*

The integrated firm responds by adjusting production, prices, stocks, merchandise mix, etc. Richardson:

> *"These actions are significantly more difficult to co-ordinate for an interdependent and nearly impossible for the independent firm."*

He concludes that the operational flexibility of the integrated firm matches the flexibility required by the competitive environment:

> *"Integration of manufacturing and retailing provides the controllability that is needed to achieve the overall operational flexibility of quick response"*

10.9.12 Richardson ignores the problem of chain control in these statements. He argues that vertical integration provides a more direct control, which is certainly true in a centralised procedural model of management. However, he underestimates the complexity and communication requirements of an unpredictable heterogeneous world (see Chapter 4.7). Enlarging the scope will add extra complexity to this situation. Indicative is the move many companies have made towards a business unit structure, in their attempt to achieve the exact opposite (and failing because of the inability to create emerging self-organising properties between those business units).

10.9.13 As there are no buffers and the nodes are not tied together through fixed links, positive feedback might easily bring the supply chain to a complete standstill. Therefore some overall control system for key performance parameters is required to keep them within the boundaries. This might take the form of every node in the chain having insight in its own contribution to the eventual process result. So instead of adjusting to the next node in the chain, every node now works towards fulfilling the eventual customer’s order. This makes it possible for all nodes to start simultaneously, in fact creating the ‘train’ movement within the ‘military convoy’ format. The elaboration of such a system requires further research (see Chapter 13).

10.10 Conclusions

10.10.1 In this chapter we addressed the consequences of creating supply chains capable of supplying a much wider variety without incurring the cost of complexity which is so central to industrial systems. It has been argued that nor conventional solutions, nor the solutions as put forward under the heading mass-customisation and postponement do provide answers once unpredictable heterogeneity approaches infinity, the consequences of such individuality cannot be catered for in the last step of the supply chain process.

10.10.2 The solutions necessary for such situations do only imply a rich solution-landscape, but also an effective interaction between the client and this landscape, implying responsiveness to be the key parameter rather than flexibility. With that the key parameter of supply chain systems becomes throughput time rather than lowest efficiency, more precisely finding better combinations between high responsiveness and resource utilisation.

10.10.3 Although supply chains systems designed along this line of reasoning are not known to be available in the physical reality, some life examples illustrate the principle. And, especially in virtual supply chains, the first examples implementing some of these principles are coming about. Yet as creating such supply chains has profound consequences for the way we look upon information and information exchange, as well as the way in which we organise our human resources within the company, more questions have to be answered before we will be capable to fully benefit from such insights. These topics will be addressed in the next few chapters.

[i] Besides the perspective of supplier efficiency, there is another common argument advocating assortment reduction. Provided that the cost of complexity problem at the supplier had been solved, there would still be the problem of search cost for the customer. By reducing the assortment, the customer's search cost could also be reduced. In this way, however, the complexity problem is still off-loaded to the customer by offering less product variety. This problem can be solved, as demonstrated in Chapter 9, by mass individualising the interaction process between the customer and the supplier.

[ii] While this certainly holds true for most incremental technological developments, a radical technological jump might produce a much more fundamental shift to the complexity cost curve. E.g., in printing industry, the development of digital printing technology has led to genuine individualisation achieved at cost parity. This does not prevent, however, that once complexity cost problems have been solved in the supply processes, the complexity problem will shift to other fields (e.g. the supplier's after sales service process, the marketing interfaces, the customer's work processes).

[iii] The phrase 'mass customisation' was coined by Davis (1987), who defines it as: "the production and distribution of customised goods and services on a mass (cost) basis."

[iv] Deere developed a 'genetic algorithm' to produce the schedule. Genetic algorithm software, originally developed at the University of Michigan, formalises the process of natural selection to allow solutions to emerge, rather than be calculated. Each night at Deere, a stand-alone PC on the factory floor downloads data from the plant's database and generates an initial set of trial schedules. These schedules are then permitted to 'breed', or recombine to create new and improved schedules. Each successive schedule is tested for fitness - whether it produces a more efficient throughput than the others generated during that iteration - and the fittest schedules are selected to breed with each other and produce new generations. Evolving solutions, rather than engineering them, is the essence of a complex adaptive system (CAS). Roughly 600,000 offspring schedules are generated and tested every night; the next morning's result is a schedule that's not perfectly optimal but comes very close. No worker is involved in producing the resulting work plan, other than turning on the computer and picking up the output. The solution is a product of evolution, not engineering. Deere's results have been significant. Overtime at the Moline plant has been drastically reduced, while monthly production figures have increased. Such methods do, however, need a range of adequate information 'architectures' in order to support the automatic, real-time data gathering required by the genetic algorithm approach."

[v] A slightly different, but connected concept is that of cellular manufacturing. The cells consist of a small group of machines and a team of workers collaborating in the production of a well-defined group of products or services. Rather than nodes, however, cellular manufacturing breaks up the production system into parallel flows. The essence of cellular manufacturing lies in the fact that the cells are self-managing entities, that are only presented with the overall goals they are expected to reach (the process intent) and not - as in traditional methods of supervision - with detailed instructions on how to achieve those goals. The key to successful decentralised control of such production systems lies in their information architecture. The behaviour of each level is determined partly by the autonomous operation of units at that level, partly by the overall parameters supplied by the level above (e.g. determining whether a unit or cell should be removed or newly created), and partly by data provided by the level below.

[vi] A floppy disk is supplied with this thesis, containing a computer programme for this problem. Starting the programme under Windows 95 (Tsp.exe) will demonstrate the ability to strive this 'travelling salesman' problem through recursive simplicity.