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Chemical Engineering and Co-engaging Production

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Abstract: *Co-engaging Production is an emerging industrial paradigm. It revolutionizes value chains and the way research and development is done. It will debunk contentions such as the over-arching belief in the benefits of mass production and economies of scale. After a period of a dominance of centralized production in large production facilities in many industries, Co-engaging Production will mean a renaissance of decentralized production. Co-engaging Production will empower consumers to become "prosumers", i.e., consumers who are also part-time or full-time producers. Co-engaging Production will engage the crowds in product development. The principles underpinning Co-engaging Production were originally developed for manufacturing value chains, i.e., the production of discrete products. Co-engaging Production has the potential to change Chemical Engineering and the chemical industry. The implementation of the principles of Co-engaging Production to the very different context of Chemical Engineering will not be a straightforward matter. The objective of this conceptual study is to envision the various effects that the adaption of the principles of Co-engaging Production will have on Chemical Engineering and the chemical industry. The contribution of this study is that it addresses key issues of operational strategy of the chemical industry in the context of value chains based on Co-engaging Production: (i) It demonstrates that innovative engineering and powerful ICT enable a renaissance of decentralized production (contrary to the arguments used in Industrie 4.0); (ii) Product-related and process-related research and development will be affected as product and process requirements change; (iii) Environmental management will be effected as a result of a proliferation of numerous production facilities, particularly when small-scale decentralized production facilities are clustered in urban centres; (iv) The viability of traditional intellectual property rights will become questionable in decentralized production value chains spanning multiple jurisdictions; and (v) The ongoing energy transition and decarbonisation will increase decentralized renewables-based energy generation enhancing Co-engaging Production.*

Keywords: *Decentralized Production, Environmental Protection, Intellectual Property Rights, Operational Strategy, Prosumer, Research and Development*

1. INTRODUCTION

Chemical Engineering and the chemical industry are on the verge of a revolution in their operational strategy [1]. The revolution in operational strategy is already discernible in discrete manufacturing and in energy generation. In manufacturing, low-cost mass manufactured products are being replaced with products manufactured individually or in small batches [2]. In the literature, the focus has been on firms moving from the large-scale production of standardized products to the production of more or less individualized products ([2], [3]). This focus fails to recognize two issues. First, the dynamic toward individualized products can result in the production being performed by individuals and home-based very small firms instead of firms. Second, more or less fluid networks are increasingly capable of offering the benefits of a firm without the disadvantages of rigid structures – this may make firms unnecessary in some instances.

The revolution that entails the decline of the dominance of centralized production and a renaissance of decentralized production is enabled by innovative engineering and powerful ICT (Information and Communications Technology). An effect of the revolution is that individuals can consume what they have produced, i.e., they become prosumers The revolution is exemplified by small-scale decentralized electricity generation with solar panels on the roofs of residential buildings for the individual's own use, and decentralized small-scale home-based discrete manufacturing with 3-D printers.

Powerful ICT makes it possible for individuals to manage even complex value chains consisting of numerous individuals and firms. This is a possibility that did not exist before, and it changes to feasibility of decentralized in the production of different products. The result is that value chains can become fluid, i.e.,

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value chains are created ad hoc. Value chains can be characterized as modular in the renaissance decentralized production. Studies on modularity in operational strategy suggest that more new products are being created [4]. A greater number of new products is a challenge for production processes, raw materials, intermediate products and final products used as input factors in decentralized production. Thus, they are a challenge for Chemical Engineering and the chemical industry.

The convergence of consumer and producer calls into question much of the past research on environmental dynamism and organizational adaptation. The past research has been based on the assumption that that the dynamism is external to the producer, and that a producer needs to adapt to dynamism in order to be able to sell its products to its customers ([5], [6]). This assumption does not hold in the case of prosumers engaging in decentralized production: As the producer the consumer defines the dynamism as it relates to production and the production. Dynamism is an internality instead of an externality.

The internationalization of dynamism has important ramifications for operational strategy in the chemical industry and Chemical Engineering. The role of them both is to support the prosumer in realizing the dynamism defined by the prosumer instead of attempting to adapt to the rapid dynamism and contradictory demands from millions of prosumers – an attempt that would be doomed to fail in view of the literature on environmental dynamism and organizational adaptation ([7], [8]). The solution lies in flexibility – flexible processes, and flexible raw materials, intermediate products and final products.

Drawing from the analysis of commitment versus flexibility by Ghemawat & Sol [9], an individual engaging in decentralized production has to use flexible equipment, because the individual does not have the resources to commit to specialized equipment. Flexibility is defined as "the ability to change or react with little penalty in time, effort, cost or performance" [10].

The revolution in operational strategy will not stop at the gates of Chemical Engineering and the chemical industry (in a broad sense). The revolution does not only encompass production, but it is an expression of a profound discontinuity in society. The revolution ends the dominance of centralized production characterized by ever more standardized products and ever larger production facilities taking advantage of economies of scale. The revolution ushers in a renaissance of decentralized production characterized by individualized products and small-scale home-based production. The contemporary iteration of decentralized production is Co-engaging Production. It is incumbent on Chemical Engineering and the chemical industry to engage in research, development and innovation that results in processes and products needed in decentralized production. The objective of this conceptual study is to envision the various effects that the adaption of the principles of Co-engaging Production will have on Chemical Engineering and the chemical industry.

2. FORCES OF CHANGE

The revolution in operational strategy must be considered against its historical backdrop. Until the late 17th and early 18th centuries, Chemical Engineering was effectively limited to small-scale operations. The establishment of the Manufacture royale de glaces de miroirs (glass), the Manufacture de Vincennes (porcelain) and the Fonderie Royale du Creusot (iron) were examples of a move toward centralized production and larger production facilities in the chemical industry. The First Industrial Revolution particularly in France and the United Kingdom strengthened the trend toward bigger production facilities, a trend that was further strengthened by the Second Industrial Revolution in the late 19th century.

Three crises have combined to herald the end of the dominance of the Occidental operational strategy of centralized production: (1) The economic malaise in the Occident commencing in the 1970ies; (2) the relative decline of the Occident; and (3) a health and environmental crisis.

The first crisis destabilized one of the cornerstones of centralized production in the 1970ies and 1980ies: the standardization of products. This crisis has been mostly confined to discrete manufacturing and had only a limited impact on the chemical industry until recently. A dichotomy could still be observed at the beginning of the 1990ies: Large firms took advantage of economies of scale and produced low cost standardized products, and small firms were flexible [11]. This was about to change.

Evolutionary change in operational strategy within the confines of centralized production was proposed and implemented: Manufacturing concepts like Flexible Manufacturing, Mass Customization, Agile Manufacturing and Fit Manufacturing have not necessarily put centralized production into question ([12], [13], [14], [15]). In Germany, innovative engineering (particularly as it relates to robotics) and ICT envisioned in Industrie 4.0 are still seen in the context of more flexible centralized production ([16], [17]). They are seen as a threat to small- and medium-sized firms [16]. Similarly, 3-D printing has also been seen as a way to improve centralized production [18].

A very different path is arguably more feasible: The renaissance of decentralized production. Innovative engineering and ICT make it feasible to abandon centralized production in favour of decentralized production. The reason for this is that economies of scale and product standardization have largely disappeared, and this has shifted the focus of operational strategy on the individualization of products. This is realized in operational strategies like Co-engaging Production, and its cousin Social Manufacturing [19], see Figure 1.

	Crafts	Mass Production	Mass Customization	Co-Engaging Production
Individualization	X			X
Customization			X	
Mass Product		X		

Figure 1: *Co-engaging Production is a renaissance of the Crafts as the individualization pf products is made feasible at costs which are competitive with those achieved in Mass Production (Mass Manufacturing) and Mass Customization. The difference of customization and individualization is that in customization the consumer's choices are limited by pre-defined options, and in individualization they are not.*

The second crisis – for the Occident – is the relative decline of the Occident. The renaissance of particularly China and India has commenced the dynamic toward the end of the dominance of the Occident. The recent dominance of the Occident has forced the non-Occidental countries to adopt Occidental engineering and operational strategies, because the non-Occidental countries have produced for and exported to the Occident. With the strengthening of the domestic economies in non-Occidental countries will create a significant additional demand for products congruent with the domestic traditions. The current dominance of Occidental engineering and operational strategies does not mean that there would not be foundations for a renaissance of non-Occidental engineering and operational strategies – particularly in countries with syncretic traditions. Decentralized production is a promising way to mobilize non-Occidental engineering and operational strategies, because people cognizant of them can participate in production.

The third crisis is a health and environmental crisis effectively caused by Occidental operational strategies. The emphasis on economies of scale has had the result that a widening rift has emerged between operational and ethical (and moral) decision-making. Operational decision-making has become a domain of firms, but ethics and morals are matters for individuals. The rift has become wider as a result of policies based on the work of Hayek [20], because government action to protect human health and the environment has been considered illegitimate. The hazardous air quality as the result of nitrous oxides and particulates emissions is a threat to human life. The World Bank [21] estimated that 5.5 million people died because of air pollution in 2013. Greenhouse gas emissions are a threat to, e.g., coastal cities as the result of a rising sea level. A new operational strategy is needed, and this is a renaissance of decentralized production in the form of Co-engaging production. A challenge will be that many of the regulations and much of the infrastructure have been designed to deal with emissions from centralized production. As the revolution to decentralized production gains ground, regulations and the infrastructure need to be overhauled.

3. CO-ENGAGING PRODUCTION

What is Co-engaging Production? Co-engaging Production encourages consumer to unleash their capabilities, competences and creativity throughout the value chains. The interactions between the (self-selected) actors are dynamic: The interactions change from product-to-product and over time. The resulting products reflect the needs and motivations of the customer thus allowing for more individualized products, better customer satisfaction and improved sustainability. Co-engaging Production validates the point made by Goldhar & Berg [22] that production and service are converging. Consumers are producers, or prosumers, in decentral small-scale operations.

Co-engaging Production addresses the three features. First, Co-engaging Production is about the individualization of processes and products. Second, Co-engaging Production means that the products are produced where they are consumed. Third, Co-engaging Production brings process- and product-related decision-making into the hands moral agents, i.e., individuals.

Co-engaging Production will not completely substitute large-scale production operations. It remains to be seen to which degree and in which cases a substitution of centralized production with decentralized production will take place. In spite of this, Co-engaging Production will affect the processes and products in Chemical Engineering and the chemical industry.

The flexibility associated with Co-engaging Production can take different shapes. Wheelwright [23] argued that flexibility encompasses volume flexibility and product flexibility. Although smaller chemical reactors address the challenge of product flexibility without significant volumes of off-quality product, product flexibility requires more: The production line has to be adaptable to different configurations, and the entire production system has to be able to handle a wide range of reactants over a wide range of temperatures, pressures and concentrations. Along with the size of the chemical reactors, the materials used in the manufacturing of chemical reactors and different parts of the production lines pose a challenge to Chemical Engineering in Co-engaging Production.

4. IMPLICATIONS FOR CHEMICAL ENGINEERING AND THE CHEMICAL INDUSTRY

The revolution of operational strategy away from a dominance of centralized production toward a dominance of decentralized production in the form of Co-engaging Production will fundamentally challenge chemical engineering and the chemical industry. The revolution will create a demand for equipment and processes used in decentralized production, and it will create a demand for raw materials, intermediate products and final products. The fragmentation and different location of the points of demand will call into question siting of the production of chemical products, sales and logistics. The reduction of retooling times toward zero will require changes to the products offered by the chemical industry. The products offered by the chemical industry have to be developed to allow safe and environmentally responsible handling in decentralized production by individuals with limited knowledge of chemistry and chemical engineering.

4.1 Equipment and Processes

The individuals co-engaging in decentralized production do not have resources to commit to numerous specialized pieces of equipment and processes. It is necessary that the equipment can be used for a wide array of chemicals, temperatures and concentrations – this is challenging when the materials for the equipment are chosen. Flexibility requires that the equipment can be easily assembled into different processes according to the operational requirements. Chemical Engineering will have be to develop feasible small-scale processes. Some examples already exist, e.g., the miniaturization of membranes described by Jullok [24] and the success of microbreweries. Because Co-engaging Production will carried out by individuals who do not always have significant knowledge in Chemical Engineering, setting up and maintaining the equipment and processes needs to be simple.

4.2 Products

Chemical Engineering and the chemical industry will have to find solutions to challenges relating to discrete manufacturing and chemicals. In discrete manufacturing, 3-D printing will play an important part. If 3-D printing is to be cost competitive, then it is necessary that the retooling time between individual print runs approaches zero. Changing the material of which the 3-D printed discrete product is printed lengthens the retooling time. Materials Science will be expected to develop materials each of which can be used across a wide range of discrete products being printed.

In chemicals, Chemical Engineering and the chemical industry will need to develop raw materials, intermediate products and final products for the use in small-scale decentralized production, including the production of chemical products (in a wide sense). Because individuals do not have the resources to store a wide array of special raw materials, intermediate products and final products, a limited number of them have to offer reasonable properties for numerous uses.

The challenge includes that the raw materials, intermediate products and final products have to be acceptable from the environmental, health and safety perspective. It has been argued that biochemical processes are complex and require sophisticated knowledge about Process System Engineering [25].

The challenge is not limited to biochemical processes. It cannot be assumed that prosumers have sophisticated knowledge on handling and working with different raw materials and intermediate products. As a consequence, the raw materials and intermediate products have to be engineered in such a way that prosumers can safely use them.

4.3 Siting, Sales and Logistics

The renaissance of decentralized production will change the distribution of the points of use of raw materials, intermediate products and final products used in production. Sales will also have to take into account that an increasing number of clients are individuals purchasing small amounts – powerful ICT will offer some potential solutions here. The changes in the distribution of use will raise the strategic issue of possibly changing the production sites and logistics to reflect the renaissance of decentralized production.

The sale to individuals with no or limited knowledge about chemistry and chemicals will raise the issue of easily understandable advice on the proper handling and use of the raw materials, intermediate products and final products being sold. The existing Material Safety Data Sheets may be too difficult to understand.

4.4 Environmental, Health and Safety

The decentralization of production will pose the challenge to develop intermediate products and final products which do not cause serious environmental issues. The decentralized production facilities will not have significant mitigation engineering at their disposal, and in urban settings the sum of emissions may be significant.

The total emissions from and environmental impact of numerous point emissions may be significant particularly in the case of a high density of decentralized production sites as will be typically the case in urban areas. In the case of effluents, this may result in a significant increase in environmentally hazardous emissions into the waterways and oceans. Because municipal wastewater treatment plants have not been designed to handle industrial-type effluent in large quantities, the change toward decentralized production will probably cause problems at municipal wastewater treatment plants. Thus, Co-engaging Production requires upgrading of municipal effluent treatment capabilities, and the equipment being used in decentralized production has to include features which can handle the volume and hazardousness of the effluent.

The materials used in Co-engaging Production contribute to solid waste streams. Two issues are of particular concern. First, the impact of the materials used have on the environment in landfills and when being incinerated requires attention. Second, the waste streams will become more complex and larger if decentralized production relies on disposable technology, a technology of increasing importance according to Allison & Richards [26]. From the environmental standpoint, recycling would be the preferred way forward, but this will require additional resources being deployed in waste management. There are some benefits: A high degree of individualization of products holds the promise that the products more closely reflect the needs of the consumers, and that the material and energy efficiency of the production of the products and the products themselves improve as a consequence.

An issue is that the concepts and tools used in the assessment of the performance of production and products from the standpoint of sustainable development, including a circular economy, are based on the assumption that firms do the production and develop the products ([27], [28]). This is not the case in Co-engaging Production.

4.5 Energy Generation and Consumption

Many chemical processes are significantly exothermal, endothermal or both depending on the stage of the production process. An extensive adoption of Co-engaged Production will thus have a significant impact on where energy generation and consumption take place and on the energy distribution system. Simultaneously, the energy sector is undergoing significant changes and a decentralization of energy generation as a result of the global combat against climate change and the need to improve air quality in major urban centres in addition to energy security considerations.

The combination and interaction of decentralized energy generation and chemical processes makes it necessary to consider energy-related analyses even more broadly than proposed by Luis & Van der Bruggen [29]. Chemical processes cannot be clearly separated from energy generation, because not only is energy generation a chemical process but chemical processes generate and use energy – this has to be considered at all stages of chemical Co-engaging Production. Additionally, Co-engaging Production and energy generation have to be considered at the level of the entire economy.

4.6 Additional Consideration: Intellectual Property Rights

Co-engaging Production will raise existential questions relating to Intellectual Property Rights (IPR). It should be noted that historically the increasing economic importance of IPR coincided with the First Industrial Revolution, i.e., mass manufacturing, i.e., centralized production. Thus, IPR can be seen as a result of and dependent on centralized production. The questions do not only relate to the factual enforceability of IPR in decentralized and global production networks spanning about 200 jurisdictions, but they also relate to the establishment and ownership of IPR when prosumers engage in product development in Co-engaging Production. The needed legal changes have the potential of significantly altering incumbent IPR-based business strategies in the chemical industry.

5. CONCLUSIONS

The implementation of Co-engaging Production will have repercussions on strategy and management in the chemical industry. Co-engaging Production will open up new business opportunities while challenging incumbent business models in the chemical industry. Co-engaging Production will also require innovation that is congruent with decentralized production from the chemical industry. Co-engaging Production is a revolution of operational strategy and tactics that requires will fundamentally change Chemical Engineering and the chemical industry.

The contribution of this paper are: (i) It demonstrates that innovative engineering and powerful ICT enable a renaissance of decentralized production (contrary to the arguments used in Industrie 4.0); (ii) Product-related and process-related research and development will be affected as product and process requirements change; (iii) Environmental management will be effected as a result of a proliferation of numerous production facilities, particularly when small-scale decentralized production facilities are clustered in urban centres; (iv) The viability of traditional intellectual property rights will become questionable in decentralized production value chains spanning multiple jurisdictions; and (v) The ongoing energy transition and decarbonisation will increase decentralized renewables-based energy generation enhancing Co-engaging Production.

The limitations of this conceptual paper requiring future research are (i) the need to perform empirical research into Co-engaging Production, and its impact on Chemical Engineering and the chemical industry; (ii) the need to perform empirical research on the environmental impact of Co-engaging Production; and (iii) the need to perform empirical research into the impact of Co-engaging Production on innovation along the value chains of the chemical industry.

Co-engaging Production will profoundly change Chemical Engineering and the chemical industry. It is necessary for the chemical industry to proactively prepare itself for these changes.

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