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Synchronized Scheduling and Order Processing as the Leverage of Digital Supply Chain Transformation Process

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Abstract
The aim of this article is to analyze and describe the relation between implemented new technologies and achieved effects of digital transformation process of the supply chains (DSC). The presented research covers seven technologies and solutions used for DSC, as compared with eleven effects of transformation process. Main finding of this paper is that for DSC transformation the most important technologies are synchronized scheduling (with mean of 3.993 in five-point scale) and flexible and dynamic order processing (mean of 3.986). Furthermore, both technologies showed highest correlations with the effects of DSC transformation process. Moreover, based on the results of factor analysis, we claim that only a decisive and comprehensive introduction of technologies related to the digital transformation of supply chains can give positive effects, while a partial implementation of DSC technologies may even worsen the company's results. The presented research allows for a better understanding of the context that determines DSC transformation, especially in the case of applied technologies and achieved effects of operations, as well as complex interdependencies between analyzed items of each variable. The results can provide foundations for digital transformation strategy of supply chains.

Keywords
Supply chain management, digital supply chain, transformation, process, technology, effects.

Introduction

In rapidly changing and disruptive environments, supply chains are increasingly exposed to risk due to many interdependent factors such as globalization and its consequences for internal and external risk occurrence, environment volatility, swift changes in customer behaviour and expectations, and so on (Aqlan & Lam, 2015; Shekariana & Parast, 2021). In the face of these fluctuations, it becomes increasingly crucial and, at the same time, more difficult to maintain the effectiveness and efficiency of supply chains (Mielcarek & Piekarczyk, 2023). The challenge of improving sustainable outcomes in the supply chains derives from the focal company policy, and the need for an integration bundle of targets combining social, economic and environmental areas (Carter & Rogers, 2008).

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Furthermore, these processes are driven by the rapid development of information and communication technology (ICT) which causes the digital disruption phenomenon (Queiroz et al., 2021). This has a range of consequences and affects economy and social interactions in basically all industries, starting from the way the business model operates, all the way through to how people – organization relations are organized (World Economic Forum, 2016; Cieśliński et al., 2017). At the same time the digital transformation of supply chains can emerge as a solution that can mitigate some of the risk and create expected value for stakeholders (Ageron et al., 2020).

Digital supply chains (DSC) are more responsive to business environment changes in comparison to traditional supply chains, as well as providing transparency for actors engaged in a whole supply chain, which fosters better decision making and communication processes (Preindl et al., 2020). DSC focus on development and the adoption of technologies "that strengthen the integration and the agility of the supply chain and thus improve customer service and sustainable organisation performance" (Ageron et al., 2020).

Despite some progress in digitalisation, understanding of DSC is in a relatively early stage (Büyüközkan & Göçer, 2018) and there are several research gaps including capabilities and the framework supporting the digitalization process of supply chains (Queiroz et al., 2021).

Based on the above, the main goal of this paper is to analyse and describe the relation between implemented technologies and achieved effects of the digital transformation process of the supply chains. Therefore, as explication, it is worth formulating a number of research questions which allow for in-depth analysis of this phenomenon:

1. Which technology plays a key role in DSC transformation process?
2. What is the interplay between specific technology and the effects of DSC transformation process?
3. What is the nature of the relationship between investment in DSC technologies and the company's achieved results?

This paper is composed of several chapters consisting of a literature review, data gathering and research sample, applied methods, empirical results, and discussion and conclusions.

Literature review

Supply chain management, in the general sense, is focused on providing the right item, with compatible quantity and condition, to the proper place at the right time and at the accepted price (Mallik, 2010). Another broader definition points out that supply chain management concerns a company's network of relationships with other organizations and internal units providing supplies of material, purchasing, logistics, production facilities, marketing, and other systems that enable two-way flows of tangible assets, finances, services, and information for the benefit of adding value, increasing profitability, and acquiring customer satisfaction (Stock & Boyer, 2009). Over recent decades, the supply chain has become more complex and internationalized, which, as a consequence of numerous turbulences (such as COVID, technological sanctions on China or the military conflict in Ukraine), is causing numerous problems and disruption in terms of SC efficiency (Jacobs et al., 2022; Pujawan & Bah, 2021; Yang, 2017). One of the directions that will partially offset VUCA environment and allow for the mitigation of these negative influences is the use of new technologies.

The use of digital technologies has enriched supply chain management methods. There are two basic approaches: the first is to analyse and focus on the entire product life cycle, including all its components and the remains of each product. The second is to take into account the processes of recording and transmitting data, which, thanks to the use of human and artificial intelligence, can be transformed into information and then into knowledge and wisdom (Paprocki, 2017).

New technologies redefine how traditional supply chains operate and accelerate reorientation towards DSC, by introducing numerous technologies, such as: Internet of Things, cyber-physical systems, big data and cloud computing, as well as blockchain (Kache & Seuring, 2017; Korpela et al., 2017; Li et al. 2018; Queiroz et al., 2021). The digital supply chain focuses on the development of information systems and implementation of innovative technologies that integrate and enhance the agility of the supply chain and as a result improves a company's sustainable performance and customer service (Ageron et al., 2020). Another, more network oriented definition of DSC, is presented by Kinnett (2015), according to whom it is "an intelligent, value driven network that leverages new approaches with technology and analytics to create new forms of revenue and business value, through a centric platform that captures and maximises the utilization of real time information emerging from a variety of sources".

DSC implementation is a rather long-term and cyclic process that not only transform relations between organisations, but also cross-functional dependencies within organisations. Moreover, to achieve a rise in supply chain performance, companies have to develop capabilities, covering digitalization to enable the proper use of technologies and integrate them with their employees, suppliers and customers throughout the whole supply chain, as well as in terms of sharing tangible and intangible assets (Ocicka & Wieteska 2017). This can be achieved by the use of ICT resource to transform physical activities to digital form, integrating both physical and digital tasks in order to minimise resource usage and improve productivity, real-time feedback, as well as network visibility, fostered by data-management tools and abilities (Queiroz et al., 2021). This point of view is also confirmed by Büyüközkan and Göçer (2018) who claim that DSC is an intelligent technological system based on the capability to display large amounts of data, provide top level communication and cooperation to synchronize and support interaction between all entities involved in the network, in order to make services "more valuable, accessible and affordable with consistent, agile and effective outcomes".

There is lengthy research on the implementation of new technologies in supply chains, such as that which concerns elements of industry 4.0 (Kache & Seuring, 2017; Korpela et al., 2017; Li et al., 2018), management perspective focusing on development of organization capabilities in digitalization of supply chain (Srai et al., 2016; Queiroz et al., 2021) or achieved company results: such as improving integration with customers and increasing efficiency of flows (Büyüközkan & Göçer 2018) and resource usage (Queiroz et al., 2021), or creating competitive advantage (Korpela et al., 2017). Moreover, implementation of new technologies into DSC improves overall efficiency, level of services, competitive value for market (Lee et. al., 2022) and reduces errors and risk in the processes (E-Fatima et al., 2022). Nonetheless, there still exists lack of sufficient and comprehensive analysis, providing wide and in-depth comparison of different technologies involved in DSC and the achieved results of operations. In order to address this research gap, it was necessary to collect quantitative raw data and subject them to statistical analysis.

Data gathering and research sample

The main goal of this paper was to analyze and describe the relation between implemented technologies and the achieved effects of the digital transformation process of supply chains. Therefore, several research questions were formulated to enable the achievement of the goal:

1. Which technology plays a key role in DSC transformation process?
2. What is the interplay between specific technology and effects of DSC transformation process?
3. What is the nature of relation between investment in DSC technologies and the company's achieved results?

Research procedure contains five stages (Figure 1).

First step of the research procedure was preliminary pilot studies with three business practitioners to check the comprehensibility of the definitions and the questions asked. Based on this feedback the survey questionnaire, covering 22 questions, was created. The primal data were obtained with use of the CAWI (Computer-Assisted Web Interview) method. The research covers two years of company operation, 2021–2022, and it was carried out in January of 2023. The study's respondents were middle-level managers and specialists in the logistic, technology or production departments.

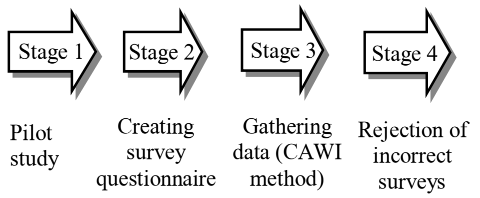

Fig. 1. Research procedure

A total of 300 responses were gathered from Polish companies with the use of a random selection method. Next, 293 responses were approved as correctly completed questionnaires and were included for further analysis.

The surveyed companies are dominated by large sized entities (39.9%), transport and warehouse management as a scope of operation (31.7%), operating more than 20 years (44.3%) and with national ownership (42.6%) – see Table 1. In terms of the implementation intensity of DSC transformation process the results are fairly even distributed, with the leading roles of building competences and modelling phase (3.672 in five-point scale). In the case of the type of entity that is important for DSC transformation, the key roles were played by buyers and suppliers (respectively 4.165 and 3.920 in five-point scale).

Table 1
Characteristics of the research sample, $n = 293$

Dominant scope of activity	Transport and warehouse management – 31.7%	Industrial processing – 16.4%	Other service activities – 41.3%	Wholesale and retail trade – 10.6%
Period of years	1–3 years – 14.8%	4–9 years – 17.5%	10–19 years –23.4%	20 and more – 44.3%
Company's ownership	National – 42.6%	International under foreign control – 22.9%		International under Polish control – 34.5%
Phase of DSC transformation	Planning and preparation for the change – 3.597	Building competences and modelling – 3.672	Implementation – 3.636	Evaluation and improvement – 3.582
Most important entities of DSC	Buyers – 4.165	Suppliers – 3.920	Competitors – 3.759	Internal departments of the company – 3.602

Applied methods

In terms of calculations, Spearman Correlation and factor analysis were applied. The first method allowed for the estimation of the covariation of two comparable data series. In terms of Spearman Correlation, all of the achieved results meet $p<0.05$ threshold.

Factor analysis was then used to evaluate the structure of data by assessing the variables' correlations. In general, the data are summarized into dimensions by assigning variables into a small group of latent factors. Those factors cannot be directly measured; however, they do allow the possibility for drawing interesting conclusions. Each original variable can be presented as a linear function of estimated factors. In terms of analysis, the percentage of variance (% Variance) indicate the portion of variance that factors explain. Moreover, each factor explains a lesser part of the variance.

A questionnaire survey containing 22 questions on a five-point scale was implemented (where: 1 – is not important, and 5 – is very important). The collected data were checked by two independent analytic sources to assure its correctness. To carry out the calculations MiniTab 2022 statistical software was applied.

Empirical Results

The first of the aspects analysed in the study is the importance of applied technologies of digital supply chain transformation (Table 2). Altogether, there are 7 implemented technologies and solutions used for DSC, which were analysed. The most important are synchronized scheduling (with mean of 3.993 on a five-point scale, standard deviation 0.933) and flexible and dynamic order processing (mean of 3.986, standard deviation 1.033).

Implemented technologies such as smart delivery (3.867) and digital platform of information exchange (3.782) turned out to be a little less important. Digitization of customer and consumer experience (3.672), digital development – intelligent product factory (3.515) and smart factory (3.468) were rated the lowest in terms of importance. To sum up for DSC transformation, the most important technologies are synchronized scheduling and flexible and dynamic order processing.

In the next stage, the effects of digital supply chain transformation were analyzed (see Table 3). The most important effects of digital supply chain transformation are the increase in work productivity (mean of 4.250), but also flexibility and the ability to adapt (mean of 4.200). The economies of scope and synergy effect (4.000) are important as well. Enterprises also noted an increase in innovations, reduction of the costs of investment activities, operating costs incurred and the time of operation.

Changes in employee retention, diversification of activities and specialization were also noticed. However, these effects were the least common in the study. But still the gap between the most important effect of DSC transformation and the least important is not very significant.

Table 2
The importance of technologies of digital supply chains, $n = 293$

Technologies of digital supply chains	Mean	Standard deviation
Synchronized scheduling	3.993	0.933
Flexible and dynamic order processing	3.986	1.033
Smart delivery	3.867	1.049
Digital platform of information exchange	3.782	1.027
Digitization of customer and consumer experience	3.672	0.959
Digital development – Intelligent product factory	3.515	1.022
Smart factory	3.468	1.064

Table 3
The effects of the digital supply chain transformation, $n = 293$

The effects of the DSC transformation	Mean	Standard deviation
Work productivity	4.250	0.812
Flexibility and the ability to change	4.200	0.815
Economies of scope and synergy effect	4.000	0.960
Innovation	3.900	0.927
Reducing the costs of investment activities	3.842	0.957
Reduction of operating costs incurred	3.789	0.928
Economies of scale	3.750	0.903
Time of operation	3.700	0.770
Employee retention	3.450	0.929
Diversification of activities	3.400	0.954
Specialization	3.350	0.904

The next analysis that can give some explanation is the correlation between applied technologies of the DSC transformation process and achieved effects of operations (see Table 4). All of the activities examined in the DSC transformation process are shown to be positively correlated and those relations are statistically significant.

There is a moderate correlation between synchronized scheduling and time of operation (0.427) as well as between synchronized scheduling and flexibility and the ability to change (0.405). Another set of relations can be found between the flexible and dynamic order processing and flexibility and the ability to change (0.438), and work productivity (0.435). Both technologies (synchronized scheduling and flexible and dynamic order processing) showed the highest correlations with

Table 4
Spearman Correlations of technologies and effects of DSC, $n = 293$

	Technologies of DSC			
Effects of DSC	Synchronized scheduling	Digitization of customer and consumer experience	Smart factory	Smart delivery
Diversification of activities	0.156	0.304	0.375	0.298
Time of operation	0.427	0.288	0.286	0.280
Flexibility and the ability to change	0.405	0.346	0.333	0.370
Work productivity	0.398	0.374	0.291	0.390
Employee retention	0.257	0.208	0.313	0.256
Specialization	0.235	0.295	0.201	0.215
Innovation	0.222	0.271	0.281	0.346
Reducing the costs of investment activities	0.242	0.369	0.260	0.269
Reduction of operating costs incurred	0.325	0.363	0.268	0.251
Economies of scale	0.346	0.254	0.307	0.198
Economies of scope and synergy effect	0.334	0.271	0.330	0.285

	Technologies of DSC		
Effects of DSC	Digital development – Intelligent product factory	Flexible and dynamic order processing	Digital platform of information exchange
Diversification of activities	0.318	0.152	0.223
Time of operation	0.248	0.366	0.361
Flexibility and the ability to change	0.334	0.438	0.360
Work productivity	0.241	0.435	0.324
Employee retention	0.268	0.239	0.287
Specialization	0.143	0.188	0.241
Innovation	0.321	0.300	0.330
Reducing the costs of investment activities	0.363	0.247	0.197
Reduction of operating costs incurred	0.386	0.320	0.285
Economies of scale	0.263	0.249	0.256
Economies of scope and synergy effect	0.374	0.295	0.385

the effects of DSC transformation process. Those observations can leverage performance of DSC, not only by a need to improve a company's technology base, but also to increase awareness of enterprises with the potential of achieving better results.

The next main point of analysis concerns factor analysis of technologies and effects of DSC (Table 5). The use of multidimensional analyses, such as factor analysis allow one to uncover more complex and hidden dependencies. Factor analysis shows, that taking the complex and comprehensive path to conduct DSC transformation process, will increases the level of all obtained effects (compare factor 1 with other factors presented in Table 5).

Altogether, there were 18 variables that indicate the designation of 18 factors, of which five will be analysed in detail. These five first factors explain 61.6% of the total variance of the variables investigated. Factor 1 (second column in Table 5) indicates that almost 38.1% of the analysed dependencies achieve positive effects with increasing implementation of technologies of digital supply chains. They achieve high positive correlation with all elements of technologies of DSC and also positive effects of DSC transformation. From this it follows that it is worth investing in technologies and solutions used for DSC, of course, if enterprises possess the resources and capabilities to do so, as, thanks to this, they achieve positive effects of DSC transformation. Particularly positive changes were noticed in increasing flexibility and the ability to change (0.662) and reduction of operating costs incurred (0.637). Implemented technologies and solutions used for DSC had also a positive impact on the increase of economies of scale (0.618) and economies of scope and synergy effect (0.620). As a result of the implementation of technologies of digital supply chains, additional positive effects were noticed, such as: work productivity (0.659), innovation, where specialization has increased with time of operation (0.617), but employee retention has decreased.

Summarizing factor 1 indicates that almost 40% of the analysed variance can be called "comprehensive" digital supply chain transformation, because it achieves high positive correlation of all the implemented technologies and solutions used for DSC and also high positive effects of DSC transformation.

Factor 2 shows different results, which explain 9% of the variance. In this case the implemented technologies and solutions used for DSC do not affect for improvement in the effects of DSC transformation. In other words there are companies that have negative correlation between applied digital technologies of supply chain and the effects of DSC transformation. It can be seen that technologies for DSC are particularly negatively correlated with specialization (–0.455) and reducing the costs of investment activities (–0.437).

In the case of factor 3, which applies to 6.6% of the variance, the situation is quite different. A positive correlation can be noticed between only some of implemented technologies and solutions used for DSC and effects of DSC transformation.

Factor 3 can be called "operational excellence" of digital supply chain transformation with focus on synchronized scheduling, flexible and dynamic order processing and digital platform of information exchange.

Factor 4 represents almost 5.3% of the variance and can be called "caring for economies of scale and synergy" of digital chain transformations. Those busi-

Table 5
Factor analysis of technologies and effects of DSC. Unrotated Factor Loadings and Communalities, $n = 293$

Variable	Factor1	Factor2	Factor3
Technologies of DSC transformation			
Synchronized scheduling	0.626	0.280	0.209
Digitization of customer and consumer experience	0.641	0.290	–0.071
Smart factory	0.651	0.349	–0.361
Smart delivery	0.644	0.399	–0.056
Digital development – Intelligent product factory	0.628	0.288	–0.433
Flexible and dynamic order processing	0.640	0.428	0.267
Digital platform of information exchange	0.620	0.334	0.026
Effects of DSC transformation			
Diversification of activities	0.485	–0.148	–0.426
Time of operation	0.617	–0.049	0.309
Flexibility and the ability to change	0.662	–0.043	0.339
Work productivity	0.659	–0.065	0.436
Employee retention	0.559	–0.296	–0.013
Specialization	0.564	–0.455	0.185
Innovation	0.595	–0.208	0.146
Reducing the costs of investment activities	0.620	–0.437	—0.221
Reduction of operating costs incurred	0.637	–0.263	–0.091
Economies of scale	0.618	–0.371	–0.168
Economies of scope and synergy effect	0.620	–0.195	–0.177
Variance	jun. 78	jan. 57	jan. 65
% Variance	**0.381**	**0.090**	**0.066**

Table continued on next page

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Variable	Factor4	Factor5	Factor6
Technologies of DSC transformation			
Synchronized scheduling	0.354	-0.193	0.126
Digitization of customer and consumer experience	–0.181	–0.288	0.284
Smart factory	–0.065	0.146	0.061
Smart delivery	–0.194	0.137	-0.051
Digital development – Intelligent product factory	–0.080	–0.018	–0.239
Flexible and dynamic order processing	0.061	–0.118	–0.055
Digital platform of information exchange	0.081	0.138	–0.062
Effects of DSC transformation			
Diversification of activities	–0.098	0.210	0.478
Time of operation	0.338	0.036	0.198
Flexibility and the ability to change	–0.129	0.147	–0.224
Work productivity	–0.150	–0.042	0.134
Employee retention	0.046	0.327	0.156
Specialization	–0.230	0.133	0.235
Innovation	–0.403	0.201	–0.348
Reducing the costs of investment activities	–0.113	–0.388	–0.092
Reduction of operating costs incurred	–0.079	–0.518	–0.102
Economies of scale	0.419	–0.056	–0.083
Economies of scope and synergy effect	0.406	0.254	–0.287
Variance	0.9561	0.9140	0.8110
% Variance	**0.053**	**0.051**	**0.045**

Variable	Factor7	Factor8	Factor9
Technologies of DSC transformation			
Synchronized scheduling	0.039	0.008	0.092
Digitization of customer and consumer experience	–0.045	0.334	0.101
Smart factory	0.105	–0.176	0.039
Smart delivery	0.090	–0.231	0.204
Digital development – Intelligent product factory	0.142	–0.158	–0.123
Flexible and dynamic order processing	0.030	0.032	0.114
Digital platform of information exchange	–0.081	0.499	–0.244
Effects of DSC transformation			
Diversification of activities	–0.428	–0.091	–0.068
Time of operation	–0.036	–0.224	–0.377
Flexibility and the ability to change	–0.139	–0.151	0.106
Work productivity	–0.064	–0.205	0.066
Employee retention	0.567	0.036	–0.190
Specialization	0.129	0.203	0.242
Innovation	–0.223	0.082	–0.177
Reducing the costs of investment activities	0.189	0.040	0.120
Reduction of operating costs incurred	–0.048	–0.065	–0.318
Economies of scale	–0.159	–0.092	0.242
Economies of scope and synergy effect	–0.099	0.195	0.134
Variance	0.7193	0.6960	0.6297
% Variance	**0.040**	**0.039**	**0.035**

nesses focus also on synchronised scheduling, flexible and dynamic order processing and digital platform of information exchange.

Factor 5 covers 5.1% of the variance and can be described as "innovation and diversification excellence" of the transformation of the supply chain. These companies focus on smart company, smart delivery and digital platform of information exchange that results in the rise of innovation, specialization and diversification of activities.

Those observations have a profound meaning for practical implications and decision making in terms of planning and executing DSC transformation process.

Discussion

Based on the above empirical results, there are several dependencies that require reference to the broader context presented in the literature on the subject. Among all of the analized technologies the leading role, in terms of shaping DSC effects, is played by two main elements. The first one is synchronized scheduling, that can be described as "synchronized decision of production scheduling and warehouse operation (...) to maximize the overall efficiency" (Luo et al., 2019). There are numerous studies that emphasize that alignment of logistics and production processes can result in cost savings of supplies, manufacturing and warehouse operation Azad et al., 2022; Li et al., 2005; Luo et al., 2017; Melchiori et al., 2022), shorter delivery lead time (Melchiori et al., 2022; Van Belle et al., 2012), helping to meet customer needs (Hilali et al., 2022; Stecke and Zhao, 2007), building robustness and shock resistance of supply chain (Luo et al., 2024) and synchronized information systems play a significant role in achieving optimized supply chain operations (Maagi, 2024) While this study goes along with those findings it also completes and emphasizes the meaning of flexibility and the ability to change the achieved result (correlation coefficient with synchronized scheduling is 0.405).

Flexible and dynamic order processing is another technology with the highest impact on DSC effects. Order processing "has direct and indirect influence on various economic and logistic objectives and thus can help to improve the flexibility of manufacturing companies" (Maier et al., 2021). Kähkönen, Evangelista, Hallikas, Immonen, Lintukangas (2021) emphasize that material and product shortages and delivery delays spread very quickly, leading to additional undesirable effects on supply chain performance and resilience deterioration (Kähkönen et al., 2021). Among the objectives influenced by order processing are the delivery time, due date compliance, inventory cost of the finished goods storage, as well as manufacturing costs (Grigutsch, 2016; Nywlt, 2015; Olhager 2003) and dynamic capabilities (Khanuja & Jain, 2023; Ramos et al., 2023). MacCarthy (2013) claims that flexibility is one of the crucial aspects of order processing and is dependent on an order processing strategy, constant technological improvement and globalization (Maier et al., 2021). Moreover, many researchers emphasize that the decision making process plays the key role in flexibility of order processing which may vary between different members in the supply chain and the time horizon of decisions (Manders et al., 2016) and costs assigned to whole supply chain and chain nodes (Wadhwa, 2008). Khanuja and Jain claim that improvement of performance is possible only for fully integrated organizations since it allows for better collaboration based on information and data sharing, as well as integration of knowledge. This "develops tight synchronisation that may result in a flexible supply chain and improve productivity" (Khanuja & Jain, 2023). Khanuja also emphasizes that supply chain flexibility (SCF) is essential to respond to customers' requirements in terms of time, ranges, volume and innovative products (Khanuja & Jain, 2023). Wang Y., Yan F., Jia F., Chen L. (2023) pay attention to the importance of managing information to develop necessary capabilities and mitigate supply chain disruptions. Flexible order processing is especially crucial since suppliers' lead time increases and it can cause delays in the delivering of the final product to the consumer and negatively affect customer satisfaction and thus can lead to decline in demand (Singh et al., 2019). On the other hand, increase of demand will cause longer order processing time, due to the need of frequent changeovers, developing employees' competences and a supplier lead time increase. The longer the delays of product delivery time, the more the capacity of warehouse inventory increases as a result (Singh et al., 2019). Therefore, those observations go along with the empirical findings of this paper, that flexible and dynamic order processing is not only responsible for agility and the ability to change but also increased work productivity (see Table 4).

Conclusions

The aim of this article is to analyze and describe the relation between implemented technologies and achieved effects of digital transformation process of the supply chains. The research procedure covers several analyses that allow for formulating the following observations and final conclusions.

All of the seven technologies implemented in digital supply chain transformation process have positive correlations with obtained effects by DSC (see Table 4). Among them there are two elements that stand out from the rest of the analyzed items. The first one is synchronized scheduling that has medium strong relationships with reducing the time of operation and improving flexibility and the ability to change (the correlations are respectively 0.427 and 0.405). The second one is flexible and dynamic order processing, which increases work productivity and flexibility and the ability to change (the correlation of those couples are respectively 0.435 and 0.438).

In general, the most important effects of DSC transformation process are work productivity (with mean result of 4.25 in 1-5 scale, see table 3) and flexibility and the ability to change (with mean 4.00). These findings support other surveys presented in the literature (MacCarthy, 2013; Maier et al., 2021, p. 267; Singh et al. 2019). But taking into account the broader perspective of DSC transformation process, it is also important to emphasize the role of other effects such as economies of scope and synergy effect, increasing innovation and reducing costs (see Table 3). Going along with this multifaceted perception, it is presented in numerous research where this approach is commonly applied in the literature on the subject (Maier et al., 2021; Mielcarek & Piekarczyk 2023; Seebacher & Winkler 2013).

Moreover, this conclusion directs one towards the use of multidimensional analyses, such as factor analysis, cluster analysis or structural equations method, that allow for the uncovering of more complex and hidden dependencies. For instance, conducted factor analysis shows that taking the comprehensive approach to conduct DSC transformation process, with complex and systematic development of all indicated technologies, makes it possible to increase the level of all obtained effects, in particular: flexibility and ability to change, work productivity and reducing operating costs incurred (compare factor 1 with other factors presented in Table 5). These observations have a profound meaning for practical implications and decision making in terms of planning and executing DSC transformation process. Based on the achieved result, a trade-off relation between investment and obtained results of DSC emerges. This creates a decision field described by two axes: 1) the number and degree of applied DSC technologies and 2) the scope of achieved results. This allows for the setting of a certain entry threshold to achieve specific results, which is outlined in the case of factor analysis (for instance see factors 3, 4, 5 or 7 presented in Table 5).

This also paves the way for further, in-depth research, which can be extended by applying further criteria presented below in the Limitations of research section.

Limitations of research

The presented research has some limitations. The first is the structure and size of the surveyed sample, which with further research could include more entities form across different countries. The second limitation considers the scope of the research. In particular, it would be interesting to analyse the role of entities in the supply chain as well as the specific order processing strategies like MTO, MTS, ETO, and ATO. The third barrier would be applied technologies and effects of DSC transformation process that certainly could be extended in order to provide a more complex and multilateral analysis. With this perspective, other statistical methods could also be considered, such as PLS-SEM, that can bring more cognitive value into the topic. The last limitation concerns cognitive errors resulting from data acquisition. The main issue is the use of a single respondent approach, which undoubtedly limits the objective assessment of the state of a given phenomenon in the entire enterprise. Additionally, many of the examined issues were assessed with a single digit, which again indicates the need for further verification of the obtained data, i.e. by applying a method for in-depth quality research.

References

Ageron B., Bentahar O., & Gunasekaran A. (2020). Digital supply chain: challenges and future directions. *Supply Chain Forum: An International Journal, 21*(3), 133–138, DOI: 10.1080/16258312.2020.181 6361.

Aqlan, F., Lam S.S. (2015). Supply Chain Risk Modelling and Mitigation. *International Journal of Production Research*, 53(18), 5640–5656.

Azad T., Rahman H.F., & Chakrabortty R.K. (2022). Optimization of integrated production scheduling and vehicle routing problem with batch delivery to multiple customers in supply chain. *Memetic Computing*, 14, 355–376, DOI: 10.1007/s12293-022-00372-x.

Büyüközkan G., Göçer F. (2018). Digital supply chain: literature review and a proposed framework for future research. *Computers in Industry*, 97, 157–177, DOI: 10.1016/j.compind.2018.02.010.

Carter C., Rogers D. (2008). A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution and Logistics Management*, 38(5), 360–387. DOI: 10.1108/09600030810882816.

Cieśliński W., Witkowski K., Piepiora Z., & Piepiora P. (2017). *The Organizational Cyberspace: E-trainerism. The Model of Advanced ICT and Augmented Reality in Sports Enterprises*, in: (eds.) M. H. Bilgin, H. Danis, E. Demir, U. Can, Empirical Studies on Economics of Innovation, Public Economics and Management: Proceedings of the 18th Eurasia Business and Economics Society Conference, series Eurasian Studies in Business and Economics, 6, 167–177, DOI: 10.1007/978-3-319-50164-2.

E-Fatima K., Khandan R., Hosseinian-Far A., Sarwar D., & Ahmed H.F. (2022). Adoption and Influence of Robotic Process Automation in Beef Supply Chains. *Logistics* 6(3), 48. DOI: 10.3390/logistics6030048.

Grigutsch M. (2016). *Modellbasierte Bewertung der logistischen Leistungsfähigkeit in Abhängigkeit des Kundenauftragsentkopplungspunktes.* Garbsen: PZH, Hannover, https://www.ifa.uni-hannover.de/de/forschung/publikationen.

Hilali H., Hovelaque V., & Giard V. (2022). Integrated scheduling of a multi-site mining supply chain with blending, alternative routings and co-production. *International Journal of Production Research*, 61(6), 1829–1848, DOI: 10.1080/00207543.2022.2049909.

Jacobs B.W, Singhal V.R., & Zhan X. (2022). Stock market reaction to global supply chain disruptions from the 2018 US government ban on ZTE. *Journal of Operation Management*, Special Issue: Global Operations and Supply Chain Management in the Context of Dynamic International Relations, 68(8), 903-927.

Kache F., Seuring S. (2017). Challenges and opportunities of digital information at the intersection of big data analytics and supply chain management. *International Journal of Operations & Production Management*, 37(1), 10–36, DOI: 10.1108/IJOPM-02-2015-0078.

Khanuja A., and Jain R.K. (2023). The conceptual framework on integrated flexibility: an evolution to data-driven supply chain management. *The TQM Journal*, 35(1), 131–152, DOI: 10.1108/TQM-03-2020-0045.

Kinnett J. (2015). *Creating a digital supply chain: Monsanto's Journey.* Washington: 7th Annual, BCTIM Industry Conference, www.slideshare.net/BCTIM/creating-adigital-supply-chain-monsantos-journey.

Korpela K., Hallikas J., & Dahlberg T. (2017). Digital supply chain transformation toward blockchain integration. In Proceedings of the 50th Hawaii International Conference on System Sciences, Hawaii, 4182–4191, DOI: 10.24251/HICSS.2017.506.

Kähkönen A., Evangelista P., Hallikas C., Immonen M., & Lintukangas K. (2021). COVID-19 as a trigger for dynamic capability development and supply chain resilience. *International Journal of Production Research*, DOI: 10.1080/00207543.2021.2009588,

Lee K., Azmi N., Hanaysha J., Alzoubi H., & Alshurideh M. (2022). The effect of digital supply chain on organizational performance: An empirical study in Malaysia manufacturing industry. *Uncertain Supply Chain Management*, 10(2), 495–510, DOI: 10.5267/j.uscm.2021.12.002.

Li K.P., Ganesan V.K., & Sivakumar A.I. (2005). Synchronized scheduling of assembly and multi-destination air-transportation in a consumer electronics supply chain. *International Journal of Production Research*, 43(13), 2671–2685. DOI: 10.1080/00207540500066895.

Luo H., Wang K., Kong X.T.R., Lu S., & Qu T. (2017). Synchronized production and logistics via ubiquitous computing technology. *Robotics and Computer-Integrated Manufacturing*, 45, 99–115, DOI: 10.1016/j.rcim.2016.01.008.

Luo H., Yang X., & Wang K. (2019). Synchronized scheduling of make to order plant and cross-docking warehouse. *Computers & Industrial Engineering*, 138, 1–17.

Luo H., Zhong Z., Tan Z., & Kong X.T.R. (2024). Synchronised warehousing and transportation operations of export containers considering supply chain disruptions. *Ocean & Coastal Management*, 251, 107070.

Mallik S. (2010). Customer service in supply chain management. In: H. Bidgoil, (ed.), The Handbook of Technology Management: Supply Chain Management. *Marketing and Advertising and Global Management*, JohnWiley & Sons Inc., NJ., DOI: 10.1108/JEIM-04-2013-0015.

Maier J.T., Heuer T., Nyhuis P., Schmidt M., (2021). The effects of hybrid order processing strategies on economic and logistic objectives, *Procedia CIRP*, 96, 266–271, DOI: 10.1016/j.procir.2021.01.085

MacCarthy B.L. (2013). An analysis of order fulfilment approaches for delivering variety and customisation. *International Journal of Production Research*, 51, 7329–7344.

Maagi B.B. (2024). Synchronization of logistics drivers for optimizing supply chain operations in Tanzania: a descriptive survey. *Journal of International Trade, Logistics and Law*, Vol. 10, Num. 1, 2024, 58–67.

Manders J.H., Canie"ls M.C., & Paul W.T. (2016). Exploring supply chain flexibility in a FMCG food supply chain. *Journal of Purchasing and Supply Management*, 22(3), 181–195.

Melchiori L., Nasini G., Montagna J.M., & Corsano G. (2022). A mathematical modeling for simultaneous routing and scheduling of logging trucks in the forest supply chain. *Forest Policy and Economics*, 136, 102693.

Mielcarek P., Piekarczyk A. (2023). Digital transformation of supply chains and company's performance. *LogForum*, 19(1), 47–57, DOI: 10.17270/J.LOG.2023.829.

Nywlt J. (2015). *Logistikorientierte Positionierung des Kundenauftragsentkopplungspunkten*, Garbsen: TEWISS, Hannover, https://www.ifa.uni-hannover.de/de/forschung/publikationen.

Ocicka B., Wieteska G. (2017). Sharing economy in logistics and supply chain management. *LogForum* 13(2), 183–193. DOI: 10.17270/J.LOG.2017.2.6.

Olhager J. (2003). Strategic positioning of the order penetration point. *International Journal of Production Economics*, 85, 319–329.

Preindl R., Nikolopoulos K., & Litsiou K. (2020). Transformation strategies for the supply chain: the impact of industry 4.0 and digital transformation. *Supply Chain Forum: An International Journal*, 21(1), 26–34, DOI: 10.1080/16258312.2020.1716633.

Pujawan I.N., Bah A.U. (2021). Supply chains under COVID-19 disruptions: literature review and research agenda. *Supply Chain Forum: An International Journal*, 23, 81–95, DOI: 10.1080/16258312.2021.1932568.

Paprocki W. (2017). *Transformacja ku gospodarce cyfrowej.* Open Eyes Book 2, 77–124.

Ramos E., Patrucco A.S., & Chavez M. (2023). Dynamic capabilities in the "new normal": a study of organizational flexibility, integration and agility in the Peruvian coffee supply chain. *Supply Chain Management: An International Journal*, 28(1), 55–73.

Seebacher G., Winkler H. (2013). A citation analysis of the research on manufacturing and supply chain flexibility. *International Journal of Production Research*, 51(11), 3415–3427.

Shekariana M., Parast M.M. (2021). An Integrative approach to supply chain disruption risk and resilience management: a literature review. *International Journal of Logistics: Research and Applications*, 24(5), 427–455, DOI: 10.1080/13675567.2020.1763935.

Singh R.K., Modgil S., Acharya P., (2019). Assessment of Supply Chain Flexibility Using System Dynamics Modeling. *Global Journal of Flexible Systems Management*, 20 (1), 39–63, DOI: 10.1007/s40171-019-00224-7

Stecke K.E., Zhao X.Y. (2007). Production and transportation integration for a maketo-order manufacturing company with a commit-to-delivery business mode. *M&SomManufacturing & Service Operations Management*, 9(2), 206–224. DOI: 10.1287/msom.1060.0138.

Stock J.R., Boyer S.L. (2009). Developing a consensus definition of supply chain management: a qualitative study. *International Journal of Physical Distribution & Logistics Management*, 39(8), 690–711, DOI: 10.1108/09600030910996323.

Srai J.S., Kumar M., Graham G., Phillips W., Tooze J., Ford S., Beecher P., Raj B., Gregory M., Tiwari M.K., Ravi B., Neely A., Shankar R., Charnley F., & Tiwari A. (2016). Distributed manufacturing: scope, challenges and opportunities. *International Journal of Production Research*, 54(23), 6917–6935, DOI: 10.1080/00207543.2016.1192302.

Queiroz M.M., Pereira S.C.F., Telles R., & Machado M.C. (2021). Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities. *Benchmarking: An International Journal*, 28(5), 1761–1782. DOI: 10.1108/BIJ-12-2018-0435.

Van Belle J., Valckenaers P., & Cattrysse D. (2012). Cross-docking: State of the art. *Omega*, 40(6), 827–846, DOI: 10.1016/j.omega.2012.01.005.

Wang Y., Yan F., Jia F., & Chen L., (2023). Building supply chain resilience through ambidexterity: an information processing perspective. *International Journal of Logistics Research and Applications*, 26(2), 172–189 DOI: 10.1080/13675567.2021.1944070.

Wadhwa S., Saxena A., & Chan F.T.S., (2008). Framework for flexibility in dynamic supply chain management, *International Journal of Production Research*. 46(6), 1373–1404, DOI: 10.1080/00207540600570432.

World Economic Forum. (2016). *World economic forum white paper digital transformations of industries: in collaboration with Accenture – societal implications*, available at: http://reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/dti-societalimplications-white-paper.pdf.

Yang L. (2017). Industry 4.0: A Survey on Technologies, Applications and Open Research Issues. *Journal of Industrial Information Integration*, 6, 1–10, DOI: 10.1016/j.jii.2017.04.005.