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Analysis of the disruptions of the digital revolution and its impacts on the evolution of continuous improvement methodologies and lean six-sigma

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Abstract

This research paper delves into the importance of continuous and lean improvements within the context of Industry 4.0. As businesses navigate the digital revolution, enhancing efficiency, effectiveness, and adaptability becomes paramount for maintaining competitiveness. The paper examines the principles of continuous and lean improvements, assessing their relevance in the Industry 4.0 landscape. Utilizing a grounded theory approach, it scrutinizes Industry 4.0 characteristics, market dynamics, disruptive forces, change management tools, and the attainment of lean operations. The findings emphasize the crucial role of continuous and lean improvements in enabling firms to navigate the dynamic Industry 4.0 landscape, effectively respond to market disruptions, and deliver enhanced value to customers. By providing actionable insights, the research paper equips companies to thrive in the digital revolution and leverage Industry 4.0 for sustainable growth. Data from 156 firms, gathered through a five-points-Likert scale questionnaire, informs the research paper. The Statistical Package for the Social Sciences (SPSS) and Analysis of Moment Structures (AMOS) software are used for statistical analyses that look at multicollinearity, content validity, and consistency, construct validity, Analysis of Variance (ANOVA), and the links between technological disruptions, the rise of agile companies, and overall performance. Results indicate that industry transformations directly and indirectly influence the evolution of Industry 4.0 and agility, empowering companies to develop effective strategies to overcome challenges posed by the digital revolution. To achieve this, companies must overhaul production systems, adopt innovative relationship management approaches, recognize and utilize existing organizational knowledge, and integrate it into product development, production operations, and marketing strategies.

Keywords: Agility, Continuous improvements, Digital revolution, Disruptions, Effectiveness, Efficiency, Industry 4.0, Lean improvements, Market forces, Value delivery.

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1. Introduction

Digital Revolution and Industry 4.0 refer to the rapid technological advancements that have transformed the way we live, work, and interact with each other. These advancements include the widespread use of digital technologies such as the Internet, artificial intelligence, automation, robotics, big data, and the Internet of Things (IoT). Industry 4.0 is a term used to describe the fourth industrial revolution, which is characterized by the fusion of digital and physical systems. It refers to the integration of advanced technologies into the manufacturing process to create smart factories that can operate more efficiently, produce higher-quality goods, and respond more quickly to changes in market demand. Digital Revolution and Industry 4.0 have transformed almost every industry, from manufacturing and healthcare to education and entertainment. The use of digital technologies has led to improved efficiency, productivity, and cost savings, as well as greater connectivity and collaboration. However, these advancements have also raised concerns about their impact on jobs and the economy, as automation and Artificial Intelligence (AI) threaten to replace human workers in many industries. There are also concerns about data privacy and security, as well as the ethical implications of using advanced technologies such as facial recognition and biometric identification. Overall, Digital Revolution and Industry 4.0 represent a major shift in the way we live and work, and they will continue to shape our society in the years to come.

1.1. Objectives and Research Items

The idea of this paper stems from the importance of searching for solutions that help companies survive and sustain themselves competitively in the face of digital and industrial revolution, where companies find themselves in confrontation with these market forces to become lean by adopting continuous improvement methodologies that enable them to focus on increasing the efficiency and effectiveness, and the turbulent surrounding industrial and technological environment imposed by the digital technologies and the Industry 4.0. Continuous improvement methodologies provide effective and critical solutions in the work of organizations, considering the digital revolution represented by Industry 4.0. Continuous improvement methodologies such as lean philosophy enable organizations to eliminate sources of waste, respond quickly to changes in the environment, take advantage of new technologies and trends, and deliver value to customers more effectively. In this paper, the concept of continuous improvement methodologies and lean six-sigma is presented and described from various aspects and linked tightly with Industry 4.0. The aim is to investigate the distinctive continuous improvement attributes that Jordanian industrial firms will possess to continue their success considering the digital revolution represented by Industry 4.0. Accordingly, to explore how that is affected by recent technological disruptions.

2. Literature Review

Industries are undergoing tremendous acceleration and rapid change recently. This accelerated change has been called the digital revolution, and Fourth Industrial Revolution, or Industry 4.0(4IR). Industry 4.0represents the current era of connectivity powered by technologies, including advanced analytics and intelligence, cloud technology, the Internet of Things (IoT), automation, Virtual Reality (VR) and Augmented Reality (AR), blockchain, and advanced manufacturing technology, that has transformed global business and industry for years and began to take hold in the mid-2010s, involving dramatic changes in operations and the future of industry.

The 4IR has put the industry in front of the challenge of rapid adaptation to face the rapidly changing factors facing production processes, as well as a competitive speed to continue producing goods and services. The digital revolution and Industry 4.0 were accompanied by significant transformations in an industry that made continuous improvement methodologies and leanness a matter of paramount importance. Some of these transformations are as follows:

1. *Rapid technology development(x_r):* A rapidly developing environment in terms of technology, materials engineering, nanotechnology, product customization, the evolution of consumer behavior, regulations, the emergence of complex supply chains, and questionable international trade stability.
2. *Information technology and telecommunications(x_i):* The daily technological development of information and communication technologies contributed to the emergence of new technologies, including digital manufacturing, connectivity-driven business models, AI, autonomous systems, the Internet of Things (IoT), electrification, cybersecurity, etc.
3. *Easy and quick access to information (x_e):*More access to information on an unprecedented scale enables organizations to act and plan according to real-time information at all levels, where synchronous data has become a need in various fields of work such as predictive maintenance, optimization, real-time performance evaluation, and detecting, diagnosing, and eliminating quality issues where they occur before moving downstream. That will give the organization a new vision.
4. *Intense competition (x_c):* Intensive competition at the local and global levels, the availability of information at a lower cost, the rapid growth in communication technologies, the tendency to produce products with shorter product lives, and the increase in environmental and ethical pressures.

Changing customers' expectations and markets. Customers are becoming more individualistic and precise in setting their expectations. Perfection, fast product delivery, and after-sales services, products with increased informational content have become a necessity. Market segmentation and the emergence of niche markets, a high rate of model changes, global competition, share market shrinking, and the need for rapid development of new products.

5. *Business relationships (x_b):* The emergence of a new form of collaboration and business relationships, including inter-enterprise cooperation, multiple forms of outsourcing, labor relationships, the increasing rate of corporate mergers, and the emergence of virtual institutions and companies.

6. *Professionalism and specialized skills (x_p):* The skills gap renders it difficult for manufacturers to recruit skilled. Workers miss many job opportunities.
7. *Societal pressures (x_s):* Commit companies to social issues such as training and education of employees, legal pressures, environmental issues, gender issues, civil rights issues, responsibility towards the poor and needy social groups, responsibility toward global disasters, the impact of conflicts between countries, and sustainability and preservation of the rights of future generations to natural resources.

In front of these technological disruptions, firms find themselves facing a confrontation with these market forces to become more efficient and effective by embracing continuous improvement methodologies and lean six-sigma that enable them to focus on eliminating sources of waste, increasing the speed of response and interaction with their customers, and the surrounding industrial environment that is characterized by technological disruptions and rapid change. Continuous improvement and lean Six-Sigma enable companies to survive and maintain future profitability in constantly changing and fragmented global markets.

2.1. Introduction to Continuous Improvement Methodologies

Continuing the contributions of Eli Whitney (1and other well-known pioneers in the field of quality and production improvement [1] the first person who truly integrate an entire production process was Henry Ford (1863-1947). Henry Ford, who revolutionized factory production in 1913, created what he called flow production, and he was able to turn the inventories of the entire company every few days. The Japanese automotive industry had to start over in the post-World War II period. Taiichi Ohno, a Toyota chief engineer (1912-1990), developed some of the basic ideas and procedures that have come to be known as continuous improvement methodologies. Ohno is the person who is given credit for initiating many of the continuous improvement methodologies.

Continuous improvement methodologies and Lean Six Sigma are prominent approaches in modern business management aimed at enhancing overall efficiency, and effectiveness. Continuous improvement methodologies are rooted in the philosophy of constantly seeking ways to enhance, the quality, and the overall performance of processes, products, and services. These methods are crucial for organizations striving to remain competitive in today's dynamic business environment. Continuous improvement methodologies have a proven track record in diverse sectors, including manufacturing, healthcare, and services [2, 3]. The choice of methodology depends on the needs and goals of an organization. Key aspects of continuous improvement methodologies include:

Kaizen: The Kaizen philosophy, which means "continuous improvement" in Japanese, and originates from Japan, has been widely adopted across industries. Kaizen led to significant operational enhancements [2].

Total Quality Management (TQM): TQM continues to be a vital aspect of continuous improvement. Recent literature highlights its role in achieving customer satisfaction and optimizing processes through a culture of quality [3]. TQM involves a commitment to quality at all levels of the organization.

Agile Principles: Combining agile and continuous improvement has gained attention as organizations seek to create a competitive advantage from a speed of response to keep pace in meeting customers' requirements and needs, in a competitive environment characterized by a continuous dynamic change. Agile practices enable companies to streamline operations and respond to customer needs more effectively [4].

Lean production: Lean production, inspired by the Toyota Production System (TPS), aims to eliminate waste, and improve efficiency in production processes. Key concepts include reducing inventory, improving flow, and optimizing resources.

Lean Six Sigma: Lean Six Sigma is a hybrid methodology that combines Lean production principles for waste reduction with Six Sigma techniques for variation reduction and quality improvements.

Furthermore, the PDCA (Plan-Do-Check-Act), developed by Walter Shewhart, serves as a foundational continuous improvement method that encompasses planning, execution, evaluation, and adaptation for ongoing enhancements [5, 6]. The 5S methodology, emphasizing workplace organization and cleanliness, aims to foster an efficient and orderly workspace [7]. Meanwhile, Hoshin Kanri functions as a strategic planning tool that aligns an organization's objectives with daily operations to ensure a collective focus on common goals [8]. The Theory of Constraints (TOC), identifies and eliminates system bottlenecks, proving particularly relevant in manufacturing contexts [9]. Benchmarking involves comparing processes and metrics to those of industry leaders [10]. Value Stream Mapping (VSM), provides a means to analyze material and information flow, uncovering inefficiencies and opportunities [11]. Table 1 goes through 30 continuous improvement methodologies.

Continuous improvement methodologies involve (1) adapting mass production to enhance worker and work cell flexibility and efficiency through waste reduction methods. (2) They result in operational systems that optimize value by eliminating waste and delays from company activities. (3) Such methodologies enable production systems to achieve more with less human effort, equipment, time, and space, aligning closely with customer demands [12].

Table 1.
Top 30 continuous improvement methodologies.

Lean principles	**Kaizen**	**Jidoka (Autonomation)**
Poka-Yoke (Error proofing)	Agile principles	Kanban
Muda, Mura, Muri	6 sigma (6σ)	SMART goals
Heijunka (Level scheduling)		
Hoshin Kanri	Overall equipment effectiveness (OEE)	Cellular manufacturing
Total productive maintenance (TPM)	Total quality management (TQM)	Value stream mapping
Single minute exchange of die (SMED)	Single piece flow	5S methodology
Standardized work	PDCA (Plan, do, check, act)	Six big losses
House of quality and quality function deployment (QFD)	Root cause analysis	Benchmarking and strengths, weaknesses, opportunities, and threats (SWOT)analysis

The philosophy of the elimination of sources of waste is achieved through striving for perfection or perfect first-time quality that necessitates a zero defect level in part quality, if the part delivered to the downstream workstation is defective, production stops. The journey towards process perfection happens gradually as continuous improvements. The acronym TIMWOODS or DOWNTIME is usually used to describe the above eight types of waste, as shown in Table 2:

Table 2.
Acronyms that usually used to describe types of waste.

Timwoods		**Downtime**	
T	= Transportation	D	= Defects
I	= Inventory	O	= Overproduction
M	= Motion	W	= Waiting
W	= Waiting	N	= Non-utilized talent
O	= Overprocessing	T	= Transportation
O	= Overproduction	I	= Inventory
D	= Defects	M	= Motion
S	= Skill set	E	= Extra processing

Diagnostic procedure can effectively address these wastes by determining their types and causes, using methods such as elimination, replacement (substitution), prevention, facilitation, detection, and mitigation. Continuous improvement is conducted one project at a time, focusing on areas such as cost reduction, quality improvement, productivity enhancement, setup and cycle time reduction, and inventory and product design improvement to boost performance and customer appeal. Another perspective on continuous improvement is to view it as a collection of proven tips, tools, and techniques (i.e., best practices) to eliminate waste and drive manufacturing process efficiency, which is critical for fostering a lean culture within the industry.

3. Conceptual Modeling

Considering the digital revolution represented by Industry 4.0. It has become necessary for firms to realize the importance of continual improvements in efficiency, effectiveness, and agility and to be able to do so, by taking advantage of the new technologies and trends imposed by the digital revolution to deliver value to customers more effectively. Thus, this research paper aims to illuminate the philosophy of continuous and lean improvements, highlighting their significance in light of the demands of the fourth industrial revolution.

To develop an inductively derived theory that meets the research objective and to answer its items, a systematic set of procedures based on the grounded theory has been followed that represents the research design. The procedures include investigating the following; (1) the characteristics of the digital revolution and industry 4.0., (2) market forces and significant disruptions in the industry that accompanied the digital revolution and industry 4.0 (3) what tools enable companies facing a confrontation with these changeable forces and drivers and how and (4) how companies become lean, how to reorganize their production systems, manage all kinds of relationships differently, recognize and value the real knowledge that has, and then employ all of that.

The previously mentioned seven industrial disruptions which will be called later "technological disruptions - (x_r, x_e, x_e, x_c, x_b, x_p, *and* x_s) are mapped and correlated to the evolution of 4.0and the philosophy of continuous improvements, and lean six sigma (Y) as shown by the structural relationships in Table 3. The focus is to investigate how the evolution of Industry 4.0 and continuous improvements and lean six sigma is caused by technological disruptions and how technological disruptions are correlated to each other. Jordanian industrial firms are considered a case study.

Table 3.
Mappings industrial disruptions with the evolution of industry 4.0and the philosophy of continuous improvements and lean six sigma (Y).

	#	Technological disruptions	Identifier
The evolution of industry 4.0and agility (Y)	1	Rapid technology development	x_r
	2	Information revolution and telecommunications	x_i
	3	Easy and quick access to information	x_e
	4	Intense competition	x_c
	5	Business relationships	x_b
	6	Professionalism and specialized skills	x_p
	7	Societal pressures	x_s

SEM, also known as Structural Equation Modeling (SEM) or path analysis, is a general model-fitting environment suitable for situations where the key constructs of interest are complex and multifaceted. It is particularly well-suited for modeling causal relationships in multifaceted systems that have multiple dependent variables, each of which can affect other dependent variables. SEMs are used to analyze the direct, indirect, or mediated effects of dependent variables on one another. As a multivariate statistical tool, SEM can be used to analyze proposed structural relationships and is sometimes referred to as covariance structure analysis models, Analysis of Moment Structures, or LISREL models. Multivariate statistics encompass various types of multivariate and univariate analyses aimed at modeling and investigating the relationships between technological disruptions [13]. These analyses aid in understanding patterns of correlations among disruptions and explain their impacts on the evolution of Industry 4.0 and lean firms. A higher-order SEM that postulates causal structuring between the seven technological disruptions and Y is shown in Figure 1, with arrows representing causal connections between variables that can be equivalently represented as equations of mathematical and statistical properties. Specific patterns of connections should appear among the SEM, these hypothesized connections are expressed in values, and the values are used to estimate the magnitudes of the causal effects among the model variables and to test for the consistency of the observed data with the postulated SEM.

3.1. Problem Statement

The main concept of interest here is the evolution of Industry 4.0 and the philosophy of continuous improvements and lean six sigma in Jordanian industrial firms, denoted as Y. It is hypothetical, latent, and not directly observable and will be called later the second-order latent variable. SEM measures Y using the first-order latent variables that cause it. The first-order latent variables that should be used to assess Y are the seven considered technological disruptions. A questionnaire on a five-point Likert scale that can be administered to a sample of Jordanian firms would be a good data collection method for measuring the implementation level of each technological disruption.

Firms that are implementing technological disruptions on a scale of 1 to 5 will respond with higher or lower answers than the true values, this discrepancy will lead to a systematic error or random error in any measured value, because the true value is causally affected by the values of some other variables see Equation 1. This situation is presented diagrammatically in Figure 1 which is the key to SEM, First and second order latent variables are represented by the ellipse shape, each observed questionnaire item is represented by a rectangle, the error variance is represented by the small circle, the single-headed straight arrow represents a directional path or employing causality which is referred to as factor loadings that express the correlation (r) between variables, it is the regression coefficient that measures the direct effect of variable, on another, and the curved double-headed arrows indicate that the technological disruptions are all correlated with one another, it is the covariance (s).

$$\text{Value}_{\text{Measured}} = \text{Value}_{\text{True}} + \text{error} \qquad (1)$$

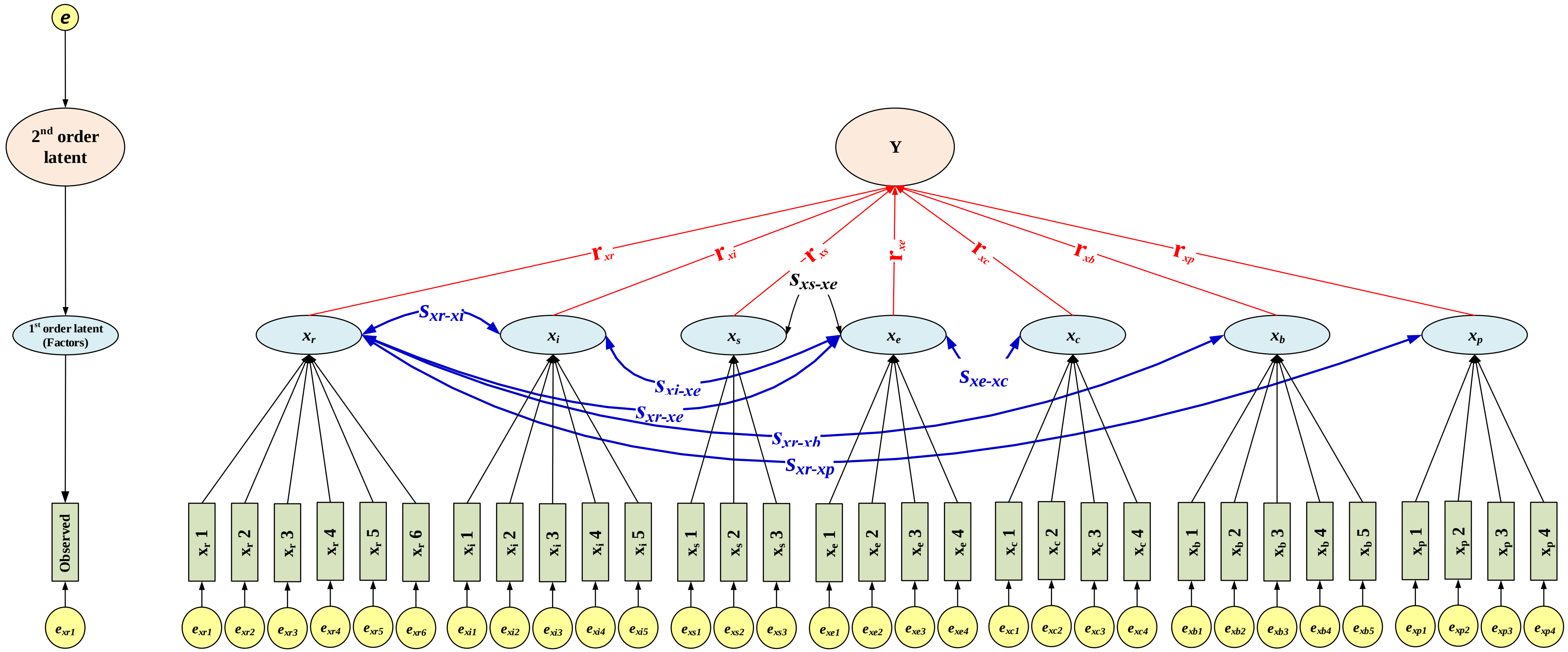

Figure 1.
Seven factors higher order SEM postulating formative indicators.

An empirical estimate for the true value, error, and loading factor corresponding to each technological disruption and questionnaire items is needed; consequently, the effects of technological disruptions on an Y criterion will be interrupted. The error and the arrows indicate that the measured score is caused by both the true score and the error. There will be variability. Variability may be due to the variation of the true level of variables across firms, systematic error, random error, and unique variants. The questionnaire design might be a source of variability, whether the questions are administered by an interviewer or completed freely by the firm representative, or if the questions are phrased in a way that makes respondents give higher ratings than their actual level. It should be noted here that the indirect effect of any questionnaire itemon Y can be estimated.

The questionnaire items in Figure 1 represent the exogenous variables that can be observed, they are independent and have only one-headed arrows coming out of them, while the variables Y, x_r, x_i, x_s, x_e, x_c, x_b, and x_p, are endogenous variables that could be independent or dependent. Variables external to the system cause exogenous variables, while variables within the system, potentially influenced by external factors or errors, cause endogenous variables. The variables x_r, x_i, x_s, x_e, x_c, x_b, and x_p, have only direct effects on Y, while the questionnaire items have only an indirect effect on Y. The number of observed variables in the model is 31 variables, accordingly, the number of non-redundant variables is ((31(31+1)/2) which equals 496, and the total number of variables to be estimated is 77, distributed into 31 error variables, 38 loading factors, and 8 latent variables. That means the proposed model is overidentified with 419 degrees of freedom. The goal of the research has now become clear: to estimate the values of the 31 errors, the 38 loading factors, and the eight latent variables.Generally, many different software packages are available for SEM analysis, such as, LISREL, Mplus, AMOS, CALIS, R, Stata, and others.

The likelihood or 'fit' of these hypotheses can be tested statistically, important hypotheses between the seven technological disruptions and their impacts on the Y hypotheses shown in Table 4.

Table 4.
Hypothesized effects between technological disruptions and Y.

Hypotheses	Null		Alternative	
H15	$H15_0$	*x_s is a cause of Y.*	$H15_1$	*x_s is not a cause of Y.*
H14	$H14_0$	*x_p is a cause of Y.*	$H14_1$	*x_p is not a cause of Y.*
H13	$H13_0$	*x_b is a cause of Y.*	$H13_1$	*x_b is not a cause of Y.*
H12	$H12_0$	*x_c is a cause of x_b.*	$H12_1$	*x_c is not a cause of x_b.*
H11	$H11_0$	*x_c is a cause of Y.*	$H11_1$	*x_c is not a cause of Y.*
H10	$H10_0$	*x_c is a cause of x_e.*	$H10_1$	*x_c is not a cause of x_e.*
H9	$H9_0$	*x_e is a cause of x_s.*	$H9_1$	*x_e is not a cause of x_s.*
H8	$H8_0$	*x_e is a cause of Y.*	$H8_1$	*x_e is not a cause of Y.*
H7	$H7_0$	*x_i is a cause of x_e.*	$H7_1$	*x_i is not a cause of x_e.*
H6	$H6_0$	*x_i is a cause of Y.*	$H6_1$	*x_i is not a cause of Y.*
H5	$H5_0$	*x_r is a cause of x_p.*	$H5_1$	*x_r is not a cause of x_p.*
H4	$H4_0$	*x_r is a cause of x_b.*	$H4_1$	*x_r is not a cause of x_b.*
H3	$H3_0$	*x_r is a cause of x_e.*	$H3_1$	*x_r is not a cause of x_e.*
H2	$H2_0$	*x_r is a cause of x_i.*	$H2_1$	*x_r is not a cause of x_i.*
H1	$H1_0$	*x_r is a cause of Y.*	$H1_1$	*x_r is not a cause of Y.*

4. Data Collection and Measurement

A questionnaire draft was developed, and it was pilot tested and reviewed by managers of several firms and the literature. From a sample of convenience that represents some Jordanian companies, the data was collected. The questionnaire is designed based on a five-point Likert scale at (1) ‘‘Poor”, (2) ‘‘Fair”, (3) ‘‘Good”, (4) ‘‘Very good”, and (5) ‘‘Excellent”. We collected responses from production managers, quality engineers, IT managers and administrator, as well as consultants. As shown in Figure 1, the construct rapid technology development (x_r) was measured by six questionnaire items, information revolution and telecommunications (x_i) were measured by five questionnaire items, easy and quick access to information (x_e) was measured by four questionnaire items, intense competition (x_c) was measured by four questionnaire items, business relationships (x_b) were measured by five questionnaire items, professionalism and specialized skills (x_p) were measured by four questionnaire items, and societal pressures (x_s) were measured by three questionnaire items.

Table 5.
Consistency and reliability of the model.

Model	Mean (μ)	Variance (σ2)	Cronbach's alpha	Index (%)
Y	61.132	27.768	0.7307	61.132

Table 6.
Some statistics of model and correlation coefficients.

Model	Technological disruptions				Correlations			Implementation index (%)		
	Identifier X_i	Item	Mean(μ_{xi})	Variance(σ^2_{xi})	Disruptions-Item	Y-Item	Y- Disruptions	Item	Disruptions	Y
Y	x_r	x_{r1}	3.224	1.607	0.349	0.297	0.629	64.480	61.688	61.132
		x_{r2}	3.122	1.308	0.393	0.337		62.436		
		x_{r3}	2.987	1.445	0.516	0.348		59.744		
		x_{r4}	3.115	1.290	0.378	0.210		62.308		
		x_{r5}	3.006	1.619	0.438	0.205		60.120		
		x_{r6}	3.051	1.649	0.449	0.198		61.020		
	x_i	x_{i1}	3.192	1.589	0.503	0.132	0.383	63.840	61.462	
		x_{i2}	3.109	1.530	0.467	0.179		62.180		
		x_{i3}	2.987	1.406	0.331	0.144		59.744		
		x_{i4}	3.109	1.659	0.590	0.214		62.180		
		x_{i5}	2.968	1.541	0.254	0.124		59.358		
	x_e	x_{e1}	3.071	1.447	0.515	0.309	0.472	61.410	59.776	
		x_{e2}	2.923	1.620	0.523	0.138		58.460		
		x_{e3}	2.981	1.542	0.442	0.251		59.616		
		x_{e4}	2.981	1.438	0.428	0.208		59.616		
	x_c	x_{c1}	3.154	1.499	0.181	0.115	0.594	63.076	62.244	
		x_{c2}	2.981	1.477	0.105	0.126		59.616		
		x_{c3}	2.840	1.542	0.000	0.024		56.794		
		x_{c4}	2.891	1.698	-0.061	0.078		57.820		
	x_b	x_{b1}	3.026	1.316	0.396	0.131	0.307	60.512	60.244	
		x_{b2}	3.051	1.623	0.502	0.200		61.020		
		x_{b3}	3.013	1.381	0.380	0.193		60.256		
		x_{b4}	3.071	1.472	0.538	0.078		61.410		
		x_{b5}	3.058	1.577	0.472	0.102		61.160		
	x_p	x_{p1}	3.135	1.550	0.585	0.142	0.286	62.692	60.340	
		x_{p2}	2.949	1.443	0.520	0.134		58.974		
		x_{p3}	3.160	1.477	0.438	0.210		63.206		
		x_{p4}	3.064	1.248	0.452	0.079		61.282		
	x_s	x_{s1}	3.038	1.676	0.578	0.153	0.496	60.760	61.132	
		x_{s2}	3.128	1.493	0.547	0.298		62.564		
		x_{s3}	2.885	1.483	0.541	0.389		57.692		

Table 7.
Inter-relations among technological disruptions and fitness indices.

Pearson correlation (-1 ≤ r ≤ 1)									**Covariance (-∞ ≤ v ≤ ∞)**							
Y	x_s	x_p	x_b	x_c	x_e	x_i	x_r	**Element**	***xr***	***xi***	***xe***	***xc***	***xb***	***xp***	***xs***	**Y**
							1.000	*xr*	105							
						1.000	0.032	*xi*	6	115						
					1.000	0.126	0.120	*xe*	14	16	138					
				1.000	0.060	0.050	0.813	*xc*	97	6	8	143				
			1.000	0.069	-0.027	-0.083	0.098	*xb*	11	-10	-4	9	124			
		1.000	0.061	-0.190	0.090	-0.005	-0.074	*xp*	-9	-0.6	13	-27	8	143		
	1.000	-0.005	-0.085	0.137	0.116	0.144	0.091	*xs*	13	21	19	23	--13	-0.7	191	
1.000	0.496	0.286	0.307	0.594	0.472	0.383	0.629	Y	34	22	29	37	18	18	36	28

Consistency validity and scale reliability are evaluated, as shown in Table 5, Cronbach's alpha value of the whole Y equals 0.8 and the Y index is 60.00%, according to George and Mallery [14]. This means that the internal consistency and overall model reliability are acceptable. Table 6 summarizes more statistical indicators like, the mean μ, the variance (σ^2), disruptions-item correlations, Y- item correlations, Y- disruptions correlations, and some other implementation indices.

4.1. Correlation and Covariance

Inter-correlations and covariance among technological disruptions are also summarized in Table 7. Inter-correlation defines how a modification of one technological disruption impacts the other, and covariance measures how technological disruptions move concerning each other.

Item-item correlations are categorized into three classes, class L implies the very weak item-item correlation ($-0.01 < r < +0.01$) , class H covers a minority of coefficients, it covers the highest correlation ($r > +0.2$, or $r < -0.2$), and the third class implies any othercorrelation value, this category includes the majority of coefficients, it covers coefficients that do not fall into class H or class L as shown in Figure 2 that depicts an interpretation of the correlation coefficients (r) values related to these three classes. Table 8 shows all cases in which the item-item correlations belongs to Classes H and L.

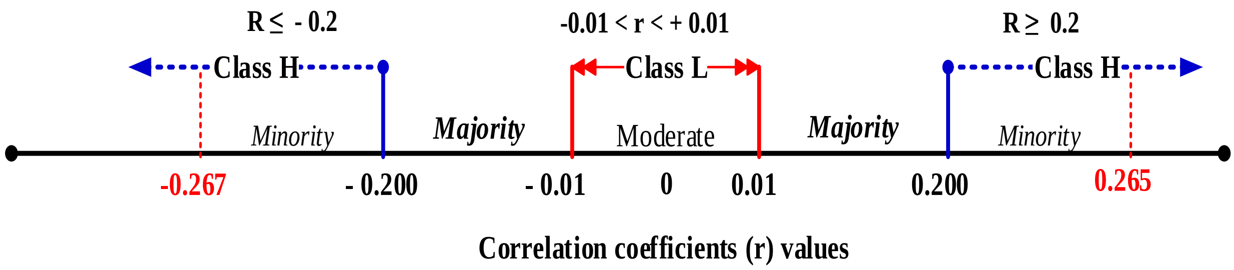

Figure 2.
Interpretation of the correlation coefficients (r).

Table 8.
Item-item correlations cases belong to class H and class L.

Item	R1	R2	R3	R4	R5	R6	I1	I2	I3	I4	I5	E1	E2	C1	C2	C3	C4	B5
R1																		
R2	L																	
R5			L															
R6	L																	
I3				L														
I4									L									
I5					H				H									
E2										L		L						
E3		H	L															
E4													L					
C1					L						L							
C2				L									L					
C3				L								L						
C4				L														
B1											L	L				L	L	
B3									L									
B4							H						L					
B5										L								
P1												L						
P2			L		L					L								
P3								L	L		L				L	H		
P4											L							
S1					L					L							L	H
S2			L			L		L				H						L
S3		L																

Note: (L: Signifies $-0.01 < r < +0.01$, H: Signifies $r > +0.2$, or $r < -0.2$), otherwise r any other value.).

4.2. Regression Analysis

Referring to Table 9, the coefficient of determination, denoted as r^2, stands at 0.9893, indicating a robust relationship between technological disruptions and Y. The F statistic assesses whether these results, characterized by such a high r^2 value, occurred randomly or not. Assuming an α value of 0.05, the critical F level is 2.069 (Excel syntax function: = F.INV.RT(α = 0.05, v1 = 7, v2 = 155)). With F = 1945.938 significantly surpassing 2.069, the likelihood of a value as high as 1945.938 happening randomly is extremely low. As a result, at α = 0.05, we reject the hypothesis that there is no relationship between Y and technological disruptions because F = 1945.938 exceeds the critical level of 2.069.

To evaluate the usefulness of each slope coefficient in assessing Y's value, the t-statistics hypothesis test is employed with α = 0.05. For testing the statistical significance of a disruption coefficient, divide the disruption'sslope coefficient by its estimated standard error. If the absolute value of the resulting t-statistic is sufficiently high, it suggests that the disruption slope coefficient is useful in assessing Y's measurement. Table 9 presents the observed t-values for each technological disruption. The t-critical value, two-tailed, with 155 degrees of freedom and α = 0.05, is 1.675 (Excel syntax function: = TINV (α = 0.05, df = 155),*TINV is a function in Microsoft Excel used to calculate the inverse of the t-distribution*). The t-statistic for each technological disruption is greater than the t-critical value of 1.675. this means that all of these disruptions are important variables when figuring out if Y is statistically significant.

Table 9.
Regression analysis: Y versus R, I, E, C, B, P, S.

Multiple R	0.995							
R-sq (r^2)	0.989							
R-sq adjusted	0.989							
Standard error (S)(Y)	0.027							
Observations	156							
ANOVA								
	df	**Adj. SS**	**Adj. MS**	**F-value**	**p- value**			
Regression	7	10.227	1.461	1945.938	0.000			
R	1	0.805	0.805	1072.23	0.000			
I	1	0.899	0.899	1197.82	0.000			
E	1	1.097	1.097	1461.73	0.000			
C	1	1.1485	1.148	1529.73	0.000			
B	1	1.007	1.007	1341.37	0.000			
P	1	1.155	1.154	1537.72	0.000			
S	1	1.466	1.467	1953.07	0.000			
Residual (Error)	148	0.111	0.001					
Total	155	10.338						
Disruption	Coefficients (m)	Standard error (SE) coef.	T-value	P-value	VIF	Lower 95.0%	Upper 95.0%	
Intercept constant	-0.040	0.027	-1.474	0.143		-0.094	0.014	
R	0.145	0.004	32.745	0.000	1.06	0.136	0.153	
I	0.145	0.004	34.610	0.000	1.04	0.137	0.153	
E	0.147	0.004	38.233	0.000	1.05	0.139	0.154	
C	0.139	0.004	39.112	0.000	1.04	0.132	0.146	
B	0.147	0.004	36.625	0.000	1.03	0.139	0.155	
P	0.147	0.004	39.214	0.000	1.03	0.140	0.154	
S	0.144	0.003	44.194	0.000	1.05	0.138	0.151	

4.3. Collinearity Test

Collinearity is a phenomenon in which one or more technological disruptions may have no additional predictive value in the presence of other disruptions. In that case, these redundant disruptions are recognized as having zero (0) coefficients and zero (0) standard error values and should be omitted from the regression analysis. Variance inflation factor (VIF) is used to test if multicollinearity is present. Variance Inflation Factors (VIF) are a measure of how much the variance of regression coefficients are inflated as compared to when the predictor variables are not linearly related. The results of the regression analysis in Table 9 showed that VIF is very close to a value of 1, which means that technological disruptions are not correlated. Based on the foregoing, the evolution level of Industry 4.0 and agile firms in Jordan can be assessed using regression Equation 2.

$$EIA(\%) = 14.5(R) + 14.5(I) + 14.7(E) + 13.9(C) + 14.7(B) + 14.7(P) + 14.4(S) - 4 \quad (2)$$

Coefficients in Equation 1 explain to what extent every single technological disruption does contribute to the evolution of Industry 4.0 and lean firms in Jordan, it is noted that they are almost equal in effect.

The probability plot in Figure 3 depicts the sample percentile with the evolution percentage (%) of industry 4.0 and lean firms. For example, in response to technological disruptions, 5% of the companies surveyed are willing at most 52.61% to adapt to Industry 4.0 and the philosophy of continuous improvements and lean six sigma, whereas 95.83% of them are willing at most 70%. In all cases, the willingness of the whole sample toward industry 4.0 and the philosophy of continuous improvements and lean six sigma did not exceed 74.42 090 in the whole sample.

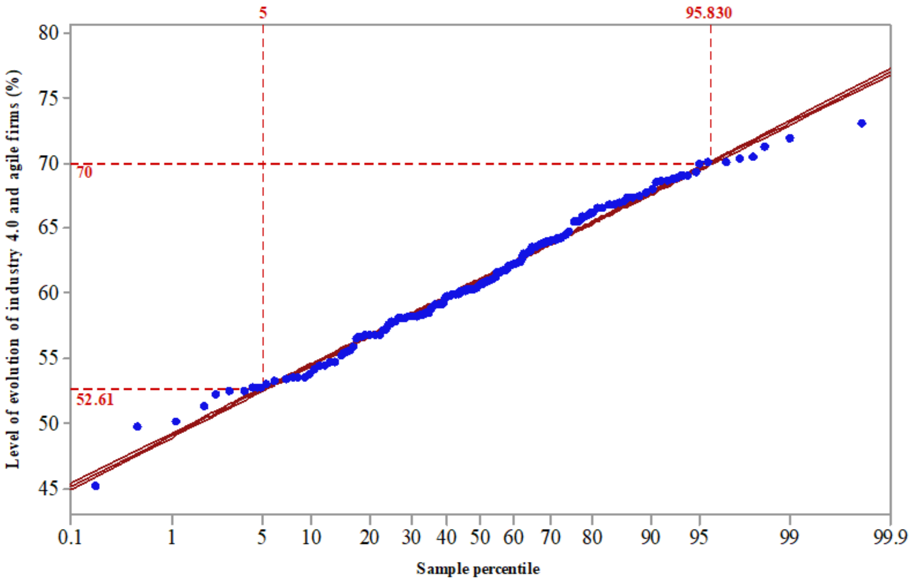

Figure 3.
Normal Probability plot output between sample percentile and level of Y.

4.4. Two-Disruption T-Test of Means

The paired sample t-test has two statistical hypotheses, the null hypothesis assumes that the true mean of disruptions is the same. Conversely, the alternative hypothesis assumes that the true mean of disruptions is not the same. These hypotheses are about the processes that produce the data and not about the data. The probability associated with a disruption's paired t-test with a two-tailed distribution, P-values of all the alternative hypotheses are calculated, then summarized in Table 10, it is observed that p-values are greater than $\alpha = 0.05$, also the absolute value of t-statistic is less than the critical value of t, (t- critical =T.INV.2T(0.05,156)) for the whole pairs, this indicates that the alternative hypotheses are false, and the null hypotheses are true, equivalently if the p-statistic is greater than or equal to than α=0.05, we reject the alternative, which is sufficient evidence that all technological disruption is an important variable when assessing Y with statistical significance.

4.5. Single-Factor Analysis of Variance

Anova-single factor analysis of variance on data for pairs of disruptions is performed. The analysis provided a test of the hypothesis that each disruption has the same variance of the underlying probability distribution against the alternative hypothesis that underlying probability distributions do not have the same variance for all disruptions. As shown in Table 11, the two-tailed ANOVA-single factor analysis at the 0.05 level revealed that influential dependencies and multicollinearity are achieved between the technological disruptions, the f-critical ($f_{0.025,\ v1,\ v2}$) exceeds f-statistic, which proves that the Y is influenced by technological disruptions under study.

Table 10.
Disruption's paired t-test with a two-tailed distribution.

Associated hypothesis	Internal correlation			Paired means test (two-tail)			Conclusion
	Variable -Variable	Pearson	t-statistic	DF	p-value	t- critical	
H15	S – Y.	0.496	-0.81	156	0.417	1.975	Same means
H14	P - Y.	0.286	0.44	156	0.662	1.975	Same means
H13	B - Y.	0.307	0.300	156	0.764	1.975	Same means
H12	C - B.	0.069	1.090	156	0.276	1.975	Same means
H11	C - Y.	0.594	1.420	156	0.158	1.975	Same means
H10	C – E	0.060	1.900	156	0.060	1.975	Same means
H9	E - S.	0.116	0.410	156	0.679	1.975	Same means
H8	E - Y.	0.472	1.640	156	0.104	1.975	Same means
H7	I - E.	0.126	1.420	156	0.159	1.975	Same means
H6	I - Y.	0.383	0.410	156	0.680	1.975	Same means
H5	R - P.	-0.074	0.110	156	0.909	1.975	Same means
H4	R - B.	0.098	0.710	156	0.480	1.975	Same means
$H3_1$	R - E.	0.120	1.630	156	0.105	1.975	Same means
$H2_1$	R - I.	0.032	0.190	156	0.847	1.975	Same means
$H1_1$	R - Y.	0.629	0.86	156	0.390	1.975	Same means

Table 11.
Anova -two-tailed - single factor.

Variables		Source of variation	SS	df	MS	f-statistic	P-value	f-critical	Conclusion
Y	S	Between groups	0.034	1.000	0.034	0.124	0.725	3.872	S and Y have the same variance
		Within groups	84.515	310.000	0.273				
		Total	84.548	311.000					
	P	Between groups	0.119	1.000	0.119	0.560	0.455	3.872	P and Y have the same variance
		Within groups	65.665	310.000	0.212				
		Total	65.783	311.000					
	B	Between groups	0.003	1.000	0.003	0.013	0.908	3.872	B and Y have the same variance.
		Within groups	58.441	310.000	0.189				
		Total	58.444	311.000					
	C	Between groups	0.400	1.000	0.400	1.724	0.190	3.872	C and Y have the same variance.
		Within groups	71.849	310.000	0.232				
		Total	72.248	311.000					
	E	Between groups	0.188	1.000	0.188	0.916	0.339	3.872	E and Y have the same variance.
		Within groups	63.756	310.000	0.206				
		Total	63.944	311.000					
	I	Between groups	0.096	1.000	0.096	0.545	0.461	3.872	I and Y have the same variance
		Within groups	54.825	310.000	0.177				
		Total	54.921	311.000					
	R	Between groups	0.168	1.000	0.168	1.022	0.313	3.872	R and Y have the same variance
		Within groups	51.088	310.000	0.165				
		Total	51.256	311.000					
C	B	Between groups	0.465	1.000	0.465	1.316	0.252	3.872	C and B have the same variance
		Within groups	109.614	310.000	0.354				
		Total	110.080	311.000					
E	S	Between groups	0.063	1.000	0.063	0.152	0.697	3.872	E and S have the same variance
		Within groups	127.595	310.000	0.412				
		Total	127.657	311.000					
I	E	Between groups	0.554	1.000	0.554	1.755	0.186	3.872	I and E have the same variance
		Within groups	97.905	310.000	0.316				
		Total	98.459	311.000					
R	P	Between groups	0.004	1.000	0.004	0.014	0.906	3.872	R and P have the same variance
		Within groups	96.077	310.000	0.310				
		Total	96.081	311.000					
R	B	Between groups	0.130	1.000	0.130	0.453	0.501	3.872	R and B have the same variance
		Within groups	88.853	310.000	0.287				
		Total	88.983	311.000					
R	E	Between groups	0.713	1.000	0.713	2.348	0.126	3.872	R and E have the same variance
		Within groups	94.168	310.000	0.304				
		Total	94.881	311.000					
R	I	Between groups	0.010	1.000	0.010	0.036	0.849	3.872	R and I have the same variance
		Within groups	85.237	310.000	0.275				
		Total	85.247	311.000					

5. Results and Discussion

5.1. Numerical Results

Data analysis using SPSS revealed that the developed SEM model is valid and fits each disruption area. At the 0.05 level, all model items had a significant impact on their technological disruption. Statistically, it is found that all the considered technological disruptions have a direct and indirect effect on Y, the average disruption's impact index on the Y is (60 %), and the average constructs' index on technological disruptions is (60 %), and constructs have a direct and indirect correlation with the overall Y model. The results may be influenced by errors due to personal reliability and trustworthiness when respondents fill out the questionnaires.

5.2. Graphical Results

Causal relationships between; the evolution of industry 4.0 and the awareness of continuous improvement programs, the evolution of industry 4.0 and the seven technological disruptions, and causal relationships among the technological disruptions are investigated, summarized as shown in Figure 4. We conduct the analysis using SPSS. Results revealed that the developed SEM model is valid and fits each disruption area. At the 0.05 level, all model items had a significant impact on their technological disruptions. Statistically, it is found that all the considered technological disruptions have a direct and indirect effect on Y, the average disruption's impact index on Y is (60 %), and the average constructs' index on technological disruptions is (60 %), and constructs have a direct and indirect correlation with the overall Y model. The results may be influenced by errors due to personal reliability and trustworthiness when respondents fill out the questionnaires.

5.3. Proposed Improvements

For firms to become lean through applying the continuous improvement programs like Lean Six Sigma, they must reorganize their production systems, manage all kinds of relationships differently, recognize and value the real knowledge that the companies have, and then employ that in the following three main areas: product development and design, production operations, and marketing.

Product development and design: Decisions related to product design determine approximately 70% of the cost of manufacturing a product. For the company to be agile, it is recommended that the designed products be characterized by the following: customizable, upgradeability, reconfigure ablility, design flexibility, design modularity, frequent model changes, information, and service platforms.

Marketing: It is important to align the company's design and marketing objectives and build an aggressive and proactive marketing plan that does not conflict with the introduction of new products at any time that enriches customers, considering the provision of after-sales services during the life of the product and competition in an effective and graceful manner.

Production Operations: Designing production lines and production facilitators in a way that allows for the reorganization of processes and procedures to comply with the agility strategy, in a way that achieves customer satisfaction at the lowest costs and in a way that achieves the reuse of processes, resources, and managing the production as part of an integrated supply chain.

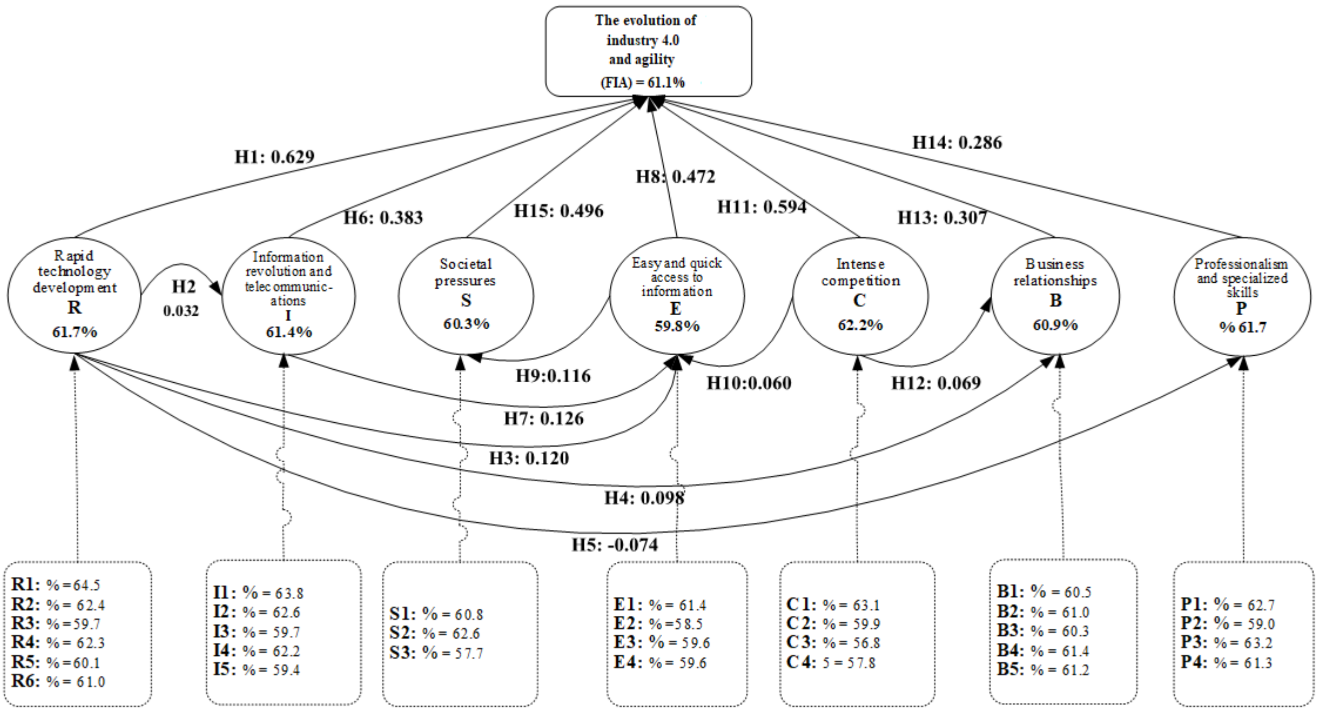

Figure 4.
The relationship between the model and its components.

5.4. Validation (11 Font)

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6. Conclusions

The impact of the implementation level of seven major technological disruptions on the evolution of industry 4.0 and agile (Y) firms is investigated using SEM methodology, IBM SPSS 20, and AMOS 19.0.0 software as an analysis tool for the purpose. The seven disruptions considered are rapid technology development (R), information revolution and telecommunications (I), easy and quick access to information (E), intense competition (C), business relationships (B), professionalism and specialized skills (P), and societal pressures (S). Results show that the implementation of technological disruptions has a significant direct and indirect impact on the Y, they contribute significantly to the emergence of agile firms. The presented approach helps to facilitate the implementation of technological disruptions in systems and to evaluate the internal correlation between its elements, and the general performance of the systems.

The main features of the digital revolution and Industry 4.0 can be summarized by, rapid technology development, information technology, and telecommunications, easy and quick access to information, intense competition, business relationships, professionalism and specialized skills, and societal pressures. These are all reasons that put companies to the test and force them to be agile to accommodate changes imposed by the digital revolution and Industry 4.0.

The literature provided encompasses a range of studies and analyses within the realm of industrial engineering and performance evaluation. AL-Tahat, et al. [15] explore various aspects of process improvement and efficiency assessment, such as the application of ordinal logistic regression models in failure mode and effects analysis (FMEA) for pharmaceutical tabletting tools [15] and the effective design and analysis of pattern-making processes using value stream mapping techniques [16]. Furthermore, Al-Tahat, et al. [17] investigate the performance evaluation and analysis of Just-in-Time (JIT)–Kanban production systems with sampling inspection methodologies [17]. Additionally, Al-Refaie, et al. [18] study the utilization of window analysis and the Malmquist index for assessing efficiency within the pharmaceutical industry [18]. Collectively, these studies contribute to the body of knowledge surrounding industrial systems optimization, process analysis, and performance enhancement strategies. In order for companies to become agile, they must be organized in a manner that facilitates rapid and flexible iteration, enabling success in the face of both predictable and unexpected change. Management of agile companies should provide necessary resources and foster a climate of mutual participation, responsibility, and internal cooperation. Collaboration with other companies is also crucial for agile competitors. Moreover, pricing strategies should be based on the perceived value of the customer rather than manufacturing costs. Achieving these goals requires companies to reorganize production systems, manage relationships differently, and recognize and leverage real knowledge across product development, production operations, and marketing domains.

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Appendix

Appendix 1 presents the questionnaire components that represent the tool used for measuring the construct variables.

Appendix 1.
Questionnaire components that represent the tool used for measuring the construct variables.

Construct variable		**Variable measure**	
		ID	**Measure**
Rapid technology development	x_r	x_r1	To what extent do you agree that the technology development is occurring rapidly in terms of advancements in materials engineering, nanotechnology, and product customization?
		x_r2	How much do you believe that the evolution of consumer behavior is happening at a fast pace in the current environment?
		x_r3	How confident are you about the stability of international trade in light of the emerging complex supply chains and changing regulations?
		x_r4	To what degree do you agree that the emergence of complex supply chains poses challenges and uncertainties in the current business landscape?
		x_r5	How much importance do you give to the impact of rapid technology development on the stability of international trade?
		x_r6	How likely do you think that the questionable stability of international trade may affect the development and adoption of new technologies?
Information technology and telecommunications	xi	x_i1	How strongly do you agree that the daily technological development of information and communication technologies has led to the emergence of new technologies, such as digital manufacturing, AI, autonomous systems, and the internet of things (IoT)?
		xi2	To what extent do you believe that connectivity-driven business models have been influenced by the advancements in information technology and telecommunications?
		xi3	How confident are you in the level of cybersecurity provided by the advancements in information technology and telecommunications?
		xi4	How important do you consider the impact of information technology and telecommunications on the development of AI and autonomous systems?
		xi5	How likely do you think that the advancements in information technology and telecommunications have contributed to the growth and adoption of the internet of things (IoT)?
Societal pressures	x_s	x_s1	How concerned are you about the impact of conflicts between countries and global disasters on the social and environmental responsibilities of companies?
		x_s2	How important do you believe it is for companies to address gender issues, civil rights issues, and social responsibility towards disadvantaged social groups?
		x_s3	How concerned are you about the impact of conflicts between countries and global disasters on the social and environmental responsibilities of companies?
Easy and quick access to information	x_e	x_e1	To what extent do you agree that easy and quick access to information enables organizations to act and plan according to real-time information at all levels?
		x_e2	How important do you believe synchronous data has become in various fields of work, such as predictive maintenance, optimization, and real-time performance evaluation?
		x_e3	To what extent do you agree that more access to information on an unprecedented scale can provide organizations with a new vision and perspective?
		x_e4	How much value do you see in the easy and quick access to information for the optimization of processes and decision-making within an organization?
Intense competition	x_c	x_c1	To what extent do you agree that there is intense competition in both local and global markets?
		x_c2	How important do you believe the availability of information at a lower cost is in contributing to intense competition?
		x_c3	How much impact do you think the rapid growth in communication technologies has on intensifying competition among companies?
		x_c4	How concerned are you about the increase in environmental and ethical

Construct variable		Variable measure	
		ID	**Measure**
			pressures impacting the level of competition in various industries?
Business relationships	x_b	x_b1	To what extent do you agree that there is a significant emergence of new forms of collaboration and business relationships in the current business landscape?
		x_b2	How important do you believe inter-enterprise cooperation is for the success of businesses in today's market?
		x_b3	How satisfied are you with the various forms of outsourcing available for businesses, such as outsourcing of certain tasks or processes?
		x_b4	To what extent do you agree that the increasing rate of corporate mergers is shaping the current business landscape?
		x_b5	How interested are you in the concept of virtual institutions and companies as a new form of business relationship?
Professionalism and specialized skills	x_p	x_p1	To what extent do you agree that there is a skills gap that makes it challenging for manufacturers to recruit skilled workers?
		x_p2	How concerned are you about workers missing out on job opportunities due to a lack of specialized skills?
		x_p3	To what extent do you agree that the skills gap is hindering the productivity and growth of the manufacturing sector?
		x_p4	How optimistic are you about the potential solutions to bridge the skills gap and improve access to specialized skills in the manufacturing industry?