Reconfigurable Supply Chains and Industry 4.0: Drivers of Enhanced Performance

Mario Roberto Acevedo-Amaya[1]; Cesar H. Ortega-Jimenez[2]; Raul Enrique Alvarado-Rivera[3]

[1,3]Universidad Nacional Autonoma de Honduras, Facultad de Ciencias Economicas, Administrativas y Contables and Universidad de Sevilla, Honduras, *mario.acevedo@unah.edu.hn, raulrivera@unah.edu.hn*

[2]Universidad Nacional Autonoma de Honduras, Facultad de Ingeniería, CURLP, Honduras, *cortega@unah.edu.hn*

Abstract*– The Fourth Industrial Revolution has driven the adoption of Industry 4.0 (I4.0) in supply chains (SCs), enhancing agility, flexibility, transparency, and competitiveness while fostering Reconfigurable Supply Chains (RECs). However, the role of I4.0 in improving the supply chain (SC) and company performance (PERF) remains unclear. Using hierarchical regression analysis and a multiple mediation model with a sample of 309 international firms, we demonstrate that RECs are primarily cost-oriented, rather than structurally reconfigurable, with only six REC enablers significantly impacting performance. The results show that I4.0 fully mediates the relationship between REC and SC performance (SCP) and partially mediates the SCP-PERF link. The findings are context-specific, limited to three industrial sectors, with potential variations across other sectors or regions due to differences in technological adoption and resources. Practically, businesses can leverage I4.0 technologies, such as IoT and predictive analytics, to enhance REC enablers like real-time integration and visibility, improving responsiveness and traceability. Thus, I4.0 is evolving from a mediator to a potential moderator in the SCP-PERF relationship.

Keywords--Industry 4.0, Reconfigurable Supply Chain, Performance, Supply Chain Performance.

I. Introduction

Due to market uncertainty [1], supply chains (SC) experience high variability, which adversely affects performance, leading to increased costs, underutilized capacity, and stockouts [2]. Constant advances in manufacturing and information technology [3] create unprecedented pressure on manufacturers, driving companies to reconfigure their production and restructure their supply chains [4] with cost-effective changes as fast as possible [2]. Therefore, to respond to market uncertainty and variability, companies must enhance the SC's agility and flexibility, implementing new paradigms such as reconfigurable supply chains (REC) and Industry 4.0 (I4.0). REC comprises six dimensions: modularity, convertibility, integrability, diagnosability, scalability, and customization [4] and originates from the field of robotics. REC is a central perspective for SC adaptation to dynamic environments [5], addressing the ripple effect (disruptions cascading through SCs) [6]. Also, it is considered a strategy to improve the SC's performance that combines a positive side, which shows innovation (related to implementing new technology [1]), and a negative side, which shows disruption risks (related to market turbulence). However, to achieve high performance, REC requires an intelligent supply chain based on I4.0 responding to innovation and disruption risk. Moreover, SC requires multidimensional capabilities and focuses on the correct set of information technology competencies, such as I4.0, to achieve a high capacity for reconfigurability [7].

Nowadays, REC performance improves when companies incorporate I4.0 (mediator effect), driven by the demand to accelerate the digitization of SC operations [8], which leads to a new manufacturing revolution paradigm [9] known as the Fourth Industrial Revolution. I4.0 emerges from market challenges and consumer demands, prompting companies to respond to market uncertainty with more agile production [10] to meet their needs quickly [11]. This paradigm enhances the organization's integration levels and the capacity to reconfigure SC more quickly to manage a higher volume of real-time data [12], adopt new technologies for data flow management [13], improve production speed, increase visibility, and SC value [14], thereby linking the computer and physical universes [10].

I4.0 adoption I4.0 has grown exponentially [15], and it is considered a fundamental way to restructure supply chains, reduce waste, accelerate manufacturing processes, and enhance flexibility, product innovativeness, agility, traceability, and overall company performance. I4.0 is the sum of all innovations implemented in the SC, including REC, to digitalize and provide real-time information about products and processes for agile reconfiguration [16]. Thus, I4.0 is considered one of the most essential factors for maximizing REC, SC, and companies' performance [17].

To respond to market demand, it is not enough to reconfigure the SC; it is necessary to know how to accelerate the gradual implementation of I4.0 in REC, without affecting the cost, and to address these demands effectively. Nevertheless, the effect of REC in combination with I4.0 has been less explored [18], and companies have been dedicated to measuring the individual contribution of REC dimensions and I4.0 applications along SC performance. However, few studies have focused on the interdependent relationship between REC, I4.0, and SC performance. Consequently, we argued that I4.0 can serve as a mediator for improving REC and can be regarded as the central perspective for enhancing SC and companies' performance in adapting to ever-changing environments [5]. Nonetheless, I4.0, REC, and their combined influence on SC performance remain underexplored in empirical research. Moreover, due to the high cost of I4.0 implementation and the investment required by REC, companies need to measure the mediating effect of I4.0 along SC and REC to understand which investments and I4.0 applications are crucial for enhancing a company's performance more effectively. Despite growing attention, theoretical and empirical gaps remain in understanding how REC and I4.0 jointly influence SC performance, and how this, in turn, impacts overall company performance. The absence of integrated models and contradictory findings on their interplay highlights a critical area of inquiry, particularly given the practical urgency of improving supply chain adaptability under volatile market conditions. Thus, this study aims to analyze the role of I4.0 in optimizing Reconfigurable Supply Chains for high performance. To achieve this, it is necessary to explore the mechanisms through which I4.0 contributes to or enhances the capabilities of REC in improving supply chain and company performance. The central research question guiding this study is: *How does Industry 4.0 mediate the relationship between Reconfigurable Supply Chains and the performance of supply chains and companies?*

II. LITERATURE REVIEW

A. Industry 4.0

I4.0 was proposed for German economic development in 2011 [19], derived from technological advances [20] implemented in SC [21]. There are more than 100 definitions of I4.0, but there is no consensus [22]. I4.0 approach integrates Manufacturing systems and Information and Communication Technologies [23] to increase vertical and horizontal integration through digital integration [24], facilitating real-time information exchange for strategic decision-making in supply chains [25]. I4.0 enables real-time communication between objects, fostering new capabilities [13], and represents an opportunity to improve the process efficiency, SC, and company performance [27] [28] while decreasing human intervention [29]. The technologies are considered the heart of I4.0 [30], and it is divided into two groups: data processing technologies (information flows) and Smart manufacturing technologies (production flows) [31].

It has as its axes (drivers of) technologies that potentially affect SC KPIs such as Cyber-physical systems (CPS); Industrial Internet of Things (IoT); cloud computing; artificial intelligence (AI) [8]; Virtual and augmented reality; Additive manufacturing; 3D printing; Simulation; Big data analytics; Cloud technology; Cybersecurity; Miniaturization of electronics; Automatic identification; Data collection (AIDC); Radio frequency identification (RFID); Robotics, drones, nanotechnology, Machine to machine communication (M2M); and Business intelligence (BI) [32] that collectively reshape supply chain behavior [33] and support the adaptation of software; sensors, processors, and communication technologies [34] that increase the levels of reconfigurability and productive efficiency [19].

I4.0 benefits include: SC reconfigurability, cost reduction, increased productivity, enhanced efficiency, and real-time visibility, which increase the supply chain's flexibility, reconfigurability, and intelligence [35]. However, the inclusion of I4.0 contributes to creating values such as: 1. Availability value – products and services offered to consumers through autonomous deliveries; 2. Digital integration value – enables transparency and traceability; facilitates process execution; allows real-time tracking of material flows across SC integration; digitizes operations; and integrates material and information flows [36].

B. Industry 4.0 and Supply Chain Performance

SC is a set of three or more entities directly involved in the upstream and downstream flows of products, services, finances, and information from their origin (suppliers) to customers [37]. SC refers to activities that produce specific or added customer value [38]. It is a crucial part of daily business that constantly evolves, integrating suppliers and customers [39]. SC system comprises material suppliers, production facilities, distribution services, and customers, all linked together through the tracking of material flows and information feedback [11]. It is measured at strategic, tactical, and operational levels [11], considering dimensions such as flexibility (enabled by I4.0), reliability, responsiveness (supported by I4.0), quality (assurance, detected and corrected by I4.0), asset management, and information sharing (facilitated through customer-supplier connectivity via I4.0).

With the entrance of the fourth industrial revolution, SC demands the digitalization of SC, but this depends on the implementation of I4.0 paradigms [9] along the SC, called SC4.0, which represents how SC coordinates using digital technologies (highlighting the mediating influence of I4.0 to reconfigure SC) [28]. Currently, there is growing evidence that I4.0 transforms SC performance, contributing to operational improvements and integrating SC processes for enhanced flexibility, responsiveness, agility, visibility, transparency, and overall performance enhancement [8]. I4.0 also enhances profitability, financial performance, innovation, customer relationships, resilience, traceability, customer satisfaction, demand shaping, and value creation [40]. It enables the customization of services based on supplier and customer requirements, provides effective communication channels, and fosters collaboration mechanisms [8]. Additionally, I4.0 technologies enhance SC performance by providing scalable information systems [45], which facilitate improved operations through more reliable and real-time information flows, enabling supplier evaluation, transparency, and uncertainty reduction [32, 46].

From a technological perspective, I4.0 supports SC through two digital technology streams: Data Processing and Smart Manufacturing [31]. These include RFID, Big Data, Cloud Computing, Robotics, Additive Manufacturing, Artificial Intelligence, and IoT [47]. The implications of I4.0 in SC are [30]: 1. It serves as a strategic lever for enhancing internal operational efficiency. 2. It allows firms to leverage supplier and customer networks to enhance value creation, and 3. It enables value-added services by utilizing data and software. I4.0 contributes to SC's focus on self-configuration for resilience, self-adjustment to variations, and self-optimization [48]. Although recent literature has recognized that I4.0 defines and contributes to the enhancement of SC performance [49], there remains a limited empirical consensus regarding the strength of its impact. Therefore, we pose the following hypothesis: *H_1: I4.0 is positive and significantly related to Supply Chain performance. H_2: The relationship between Supply Chain performance and Companies' performance increased when I4.0 participated*.

C. Reconfigurable Supply Chain

Reconfigurable SC (REC) is a modular manufacturing approach that includes component-based systems and modular product systems. It is a network designed to be cost-efficient, responsive, sustainable, and resilient, capable of dynamic structural changes in both physical and cyber spaces. This adaptability occurs through the rearrangement and reallocation of components in response to sudden changes [5]. REC evaluation occurs at two levels: at the lower level by changes in hardware resources, and at higher levels by changes in software resources, alternative methods, or flexible organizational structures [50]. Studies show that REC enhances SC performance by improving visibility for sensing, learning, coordination, and integration [51]. However, to achieve this, REC requires I4.0 as a digital enabler to interconnect SC areas and adjust productive capacities [52].

Research suggests that SC performance improves when it is rapidly reconfigured through REC, allowing the inclusion of new intelligent technologies and software linked to I4.0 [2]. REC has enablers such as: Network Structure Design, Responsiveness, Total Cycle Time, Real-Time Integration, Collaboration, Transfer Pricing, Adaptability, Leagility, Trust, Visibility, Data Reliability, Resilience, New Product Development, Customer Satisfaction, and Sustainability [2]. Also, Researchers measure REC through six key dimensions [1,4]: modularity, integrability, customization, scalability, convertibility, and diagnosability.

1. Modularity involves considering both design and user perspectives, which involves dividing systems into reusable, modular components. It reduces complexity and supports reconfiguration. A module has four aspects: Physical, Control, Simulation (I4.0 implementation), and KPI. It encompasses Network Structure Design, Responsiveness, and Total Cycle Time [2], and is evaluated based on granularity and the number of interfaces [4]. **2. Integrability** refers to the ability to incorporate new technologies into existing systems using mechanical and informational tools. It includes Real-Time Integration, Collaboration, and Transfer Pricing [2]. **3. Customization** measures the degree to which manufacturing systems match specific customer needs through flexible hardware and control systems [2]. **4. Scalability** supports cost-effective expansion, defined as the system's ability to adapt throughput to changing demand efficiently [51][44]. It depends on latency, data quality, and performance under uncertainty [2]. **5. Convertibility** refers to the ability to change production functionality or shift between products with minimal disruption to resources [51]. It involves process flexibility and is assessed through conversion increments, routing connections, and machine replication [1]. It aligns with Adaptability, Leagility, and Trust [2]. **6. Diagnosability** enables early failure detection and correction through detectability, Predictability, and Distinguishability [51]. It is measured through Visibility, Data Reliability, and Resilience [2].

REC orientations change with each dimension. Modularity, Integrability, and Diagnosability reduce reconfiguration time and effort; Customization and Convertibility focus on cost reduction [53]. Structurally, REC includes Convertibility, Integrability, and Modularity; Functionally, it includes Scalability, Diagnosability, and Customization. Indicator categories include [2]: 1. Time (Modularity, Scalability, Diagnosability); 2. Capacity (Convertibility, Integrability, Modularity); 3. Reactivity (Modularity, Customization, Diagnosability); and 4. Flexibility (Integrability, Convertibility, Diagnosability). While extensive literature supports the impact of REC on SC performance, there is limited empirical evidence on how I4.0 specifically enhances REC and SC performance. This leads to the following hypotheses: *H_3: REC is positively and significantly related to Industry 4.0. H_4: REC is positive and significantly related to SC performance. H_5: REC and I4.0 are positively associated with SC performance. H_6: REC mediates the relationship between SC and SC performance. H_7: REC and I4.0 mediate the relationship between SC performance and company performance. H_8: REC enhances SC performance and company performance, achieving high performance when integrated with Industry 4.0.*

III. METHODOLOGY

A. Questionnaire, sampling, and data collection

The data collection for this study involved an international survey using a questionnaire with 16 scales. Respondents rated items on a five-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree) to measure each research scale. The sample included plants from machinery, automotive suppliers, and electronics sectors across 14 countries. We distributed the survey to 309 companies, and only 262 provided complete responses.

B. Reliability Scales

Cronbach's alpha was up to 0.70 ($\alpha > 0.70$) [41], confirming internal consistency. We tested an Exploratory factor analysis (EFA) using the principal part and varimax methods, as inter-variable correlations were below 0.70. We consider five constructs: Reconfigurability (REC), Supply Chain (SC), Supply Chain performance (SC performance), Industry 4.0 (I4.0), and Performance (PERF). EFA results indicate that the Kaiser-Meyer-Olkin measure of sample adequacy was 0.883, suggesting that the data are suitable for factor analysis; the chi-square value was 2885.793, with 210 degrees of freedom and a p-value of $p < 0.000$ [42]. Communalities extraction was greater than 0.5. The total variance explained by the five constructs was around 63%. We assessed the total variance extracted by one factor to ensure that common method bias is not present. The total variance extracted by one factor was 31.508%, less than 50%. The standardized regression coefficients were greater than 0.50, indicating unidimensionality [42]. Additionally, we assessed the Average Variance Extracted (AVE), and the averages of values (AVE > 0.70) showed that 70% of the variation in each construct is explained by its items, confirming convergent validity. Furthermore, we measured Composite Reliability (CR), with values above 0.60, indicating internal consistency. Also, we assessed the Multicollinearity using VIF values; we concluded that Multicollinearity among the independent variables is not a problem, as the VIF values are all less than five (VIF<5). The Durbin-Watson statistic was 1.902 (value between 1.5 and 2.5).

C. Models

We used two models to test the research hypothesis. First, we used Hierarchical regression analysis to evaluate the percentage of variance explained by each independent variable (REC and I4.0) in relation to the dependent variables (SC performance and Performance). Second, we employed both simple and parallel multiple mediator models to assess indirect effects, utilizing a statistical mediation framework. Fig. 1 illustrates both direct and mediated relationships among the constructs: Reconfigurability (REC), Industry 4.0 (I4.0), Supply Chain (SC) Performance, and overall Performance (PERF). Arrows indicate hypothesized causal paths evaluated in the regression and mediation models [43].

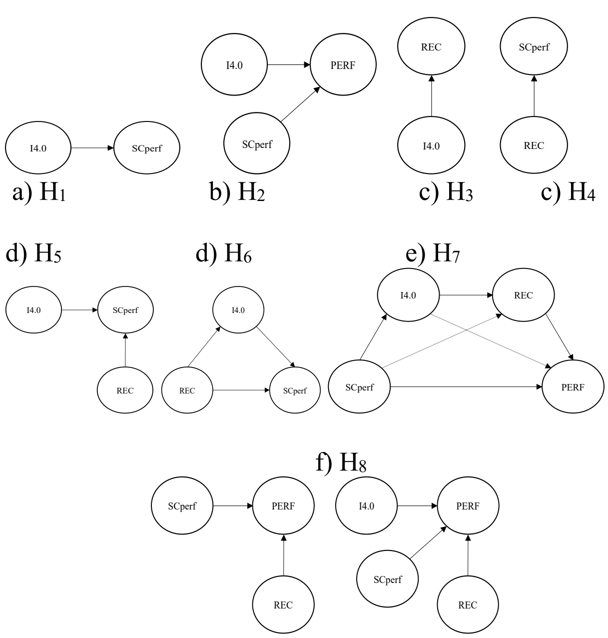

Fig. 1: Hypothesis models.

IV. Results

The correlation matrix (Table I) indicates that all variables are positively and significantly correlated. A strong positive relationship exists between SC, SCperf, and PERF. Besides, I4.0 shows a moderate and significant correlation with SC performance and REC. SC is strongly associated with SC performance and I4.0, but has a weaker association with REC. I4.0 and SC are moderately associated with REC. Table I also confirms no multicollinearity issues, supporting the stability of the regression models.

TABLE I
CORRELATION MATRIX

Mean	SD	Construct	SCperf	REC	I4.0	SC	PERF
3.792	0.53093	SCperf	1				
3.4289	0.51383	REC	.181**	1			
3.2149	0.44545	I4.0	.428**	.482**	1		
3.562	0.46252	SC	.594**	.332**	.655**	1	
3.7499	0.40062	PERF	.713**	.295**	.516**	.785**	1

A. REC, I4.0, and SC performance level

From evaluating each REC dimension (Table II) in a 5-point scale, we found that **Modularity** has an average implementation level of 3.43. Companies face difficulties adapting machines, tools, and technologies for different product families. These include challenges in mass customization, lifecycle cost variation, limited adaptability, and a lack of modular infrastructure. Modularity enablers, such as network structure design (3.96), responsiveness (4.43), and total cycle time (4.08), support modular supply chains (SCs), but some companies still lack sufficient granularity.

TABLE II
REC DIMENSION PERFORMANCE

SECTOR	Modularity	Integrability	Diagnosability	Scalability	Convertibility	Customization
Auto-supplier	3.43	3.24	3.43	*3.38*	3.26	3.55
Electronic	3.68	3.43	3.54	3.67	3.49	3.63
Machinery	*3.17*	*3.17*	*3.42*	3.47	*3.17*	*3.53*
Total	**3.43**	**3.28**	**3.46**	**3.52**	**3.31**	**3.57**

Integrability has an average level of 3.28, reflecting difficulties in adapting to new processes, products, or partners. This is especially evident in the machinery and auto-supplier sectors due to outdated systems and equipment. **Diagnosability** reached 3.46 points, with the electronics sector scoring the highest. Challenges include limited visibility, unreliable data, and slow resilience responses. **Scalability** averaged 3.5 points, indicating moderate capacity for volume flexibility. Some companies struggle with throughput and latency. Average order-to-shipment time is 55 days: 37 days (auto), 43 (electronics), 78 (machinery). **Convertibility** scored 3.31. Machinery again lags (3.17), while electronics lead (3.49). Companies show moderate market adaptability, but many have inflexible layouts and redundant lines. Shop floor layout performance (3.77) and equipment setup times (3.4) reflect limited reconfigurability.

Customization raised the highest score (3.57 out of 5). Equipment tailored to product families enhances flexibility. However, customer involvement and personalization capacity remain low. Despite strong delivery metrics—fast delivery (3.70), on-time delivery (3.8), and delivery reputation (4.13)—mass customization is constrained by moderate I4.0 integration.

TABLE III
REC, I4.0, SC, AND PERF LEVELS

SECTOR	REC Level	I4.0	SCPERF	PERF
Auto-supplier	3.35	3.34	3.66	3.69
Electronic	3.44	3.35	3.6	*3.65*
Machinery	*3.26*	*3.22*	*3.49*	3.67
Total	**3.35**	**3.30**	**3.57**	**3.67**

REC, I4.0, and SC performance were evaluated through their principal dimension using a 5-point Likert scale (1 = low level, 5 = high level). Table III shows that the three sectors evaluated show a moderate level of **REC**, with an overall implementation score of 3.30. The Machinery sector shows the lowest REC level (3.26), the Auto-Supplier sector has a level of 3.35, and the Electronics sector leads with 3.44. **I4.0** scored 3.30; the electronics and automotive sectors lead; the machinery sector lags. Plants face weak integration with SC partners, low data sharing, and underutilization of analytics systems. The limited use of the Internet and EDI tools hampers online services, dynamic pricing, order tracking, and forecasting. IT spending remains low and focused on isolated SC areas. **SC performance** (SCPERF) had a level of 3.57 out of 5, which is impacted by limited systems implementation and weak conformance and sustainability practices. However, flexibility with supplier changes (3.9) and supplier lead time (4.0) is substantial. PIDT systems help, but they require Industry 4.0 technology for end-to-end visibility. IT use remains moderate (3.2), especially for electronic transactions. **PERF** reached 3.67. All sectors exhibit moderate levels, constrained by high manufacturing costs, ineffective inventory management, limited integration, outdated technologies, and increasing labor costs. Web interfaces lack real-time connection, further affecting performance. Therefore, the REC enablers and REC constraints are summarized below (see Table IV)

TABLE IV
ENABLERS AND NOT ENABLERS OF REC

REC Enablers	Enablers with constrain to improve REC
Total cycle time	Network structure design
Adaptability and resilience	Responsiveness
Leagility	Real time integration
Trust	Transfer pricing
Collaboration	Visibility
New product development	Data reliability
Customer satisfaction	
Sustainability	

B. Hypothesis test

To test the research hypothesis (effect of I4.0 and REC on SC performance), it was necessary to test the correlation between variables and standard deviation. Table I shows a moderate but significant correlation level between I4.0, REC, and SC performance ($0.1<r<0.8$; $p<0.05$) with a standard deviation of less than 0.70, indicating low variability. Also, the statistical correlation evaluated in Table I was used to assess H1 by estimating the correlation, considering the signs and levels of association between variables. Results show a correlation coefficient between I4.0 and SC performance of r = 0.428 ($p<0.001$), indicating a positive and moderate association between these variables. Hence, we accept H_1. The empirical evidence tested in hypothesis I is consistent with the literature review, indicating that I4.0 contributes to increasing SC performance. In this case, I4.0 explains at least 40% of the variance in SC performance.

To test Hypothesis H_2, which measures the contribution of I4.0 to predict SC performance after controlling for REC (see Table V), we used Hierarchical multiple regression. The results of **Model 1 (I4.0->PERF)** were statistically significant and generalizable: ($\beta = 0.262$, $t = 4.277$, $p < 0.01$). I4.0 explained 5.6% of PERF variance, F (1,308) =18.294, $p<0.001$. R = 0.237, $R^2 = 0.056$. Then, we evaluated the results of **Model 2 (I4.0, SC performance->PERF),** where SC perf and PERF are positively and significantly associated ($\beta\_I4.0 = 0.237$, $t = 2.576$, $p < 0.01$; β_SC performance = 0.186, $p < 0.01$). The value of R^2 increased with a $\Delta R^2 = 0.020$, which implies that the inclusion of SC performance improves the PERF by at least 2%. SC performance (b=0.170, t=2.576, p<0.010) and I4.0 (b=0.230, t=3.710, p<0.000) were significant predictors of PERF.

TABLE V
HIERARCHICAL REGRESSION ANALYSIS FOR H_2

	PERF	
	Model 1 (H_2)	**Model 2 (H_2)**
I4.0	0.262**	0.237**
SC performance		0.186**
F	18.294	6.635
R	0.237	0.276
R^2	0.056	0.076
Adjusted R2	0.053	0.070
VIF	1.00	1.042
Changes in R^2		0.020
Durbin-Watson statist		1.775
t-statistic	4.277	2.576

The Durbin-Watson statistic (1.775) and VIF (1.042) indicate no evidence of multicollinearity or autocorrelation. I4.0 explained 5.6% of PERF. But, adding SC performance, PERF is explained 2% additionally. Thus, H_2 is supported (see Table V).

To test H_3, H_4, and H_5, we estimated the statistical correlation level between variables. Table III shows that REC had a moderate and significant correlation with I4.0 ($r = 0.482$, $p<0.001$) and a weak correlation with SC performance ($r = 0.181$, $p<0.001$). I4.0 and SC performance are moderately correlated ($r = 0.428$, $p<0.001$). These results support H_3, H_4, and H_5. Additionally, a regression analysis confirmed a linear dependency ($R^2 = 0.041$, $F(2,307) = 6.1513$, $p < 0.001$), validating H_5. The VIF (1.067) and the Durbin-Watson statistic (1.717) supported the integrity of the model. To test H_6, we evaluated the mediation effect, using I4.0 as a mediator between REC (independent variable) and SC performance (dependent variable) (see Table VI).

TABLE VI
SIMPLE MEDIATION ANALYSIS

	Coefficient	R	R-sq	MSE	P
REC->SCP (c)	0.25	.3224	.1039	.1444	.00
REC->I4.0 (a)	.4337	.5003	.2503	.0466	.00
I4.0->SCP (b)	.4996	.5790	.3353	.1075	.00
REC->SCP (c')	.0347	.5790	.3353	.0456	.44
Total effect X->Y	.2513			.0458	.00
Direct effect of X on Y	.0347			.0456	.44
		BootSE	BootLLCI	BootULCI	
Indirect effect(s) of X on Y:	.216	.034	.1524	.2886	

Table VI shows the results of the mediation analysis. The mediation model tested was significant ($R^2 = 0.25$, $F = 86.79$, $p < 0.001$). First, we estimated the regression analysis without the mediator variable (**REC to SC performance**). The results show a coefficient of 0.2513 ($p < 0.000$), indicating a positive and significant relationship between these variables. As a second step, we included the mediator variable (I4.0) to evaluate the regression coefficients between the independent variable and the mediator variable (**REC to I4.0**). The result was significant, $F = 86.79$, $t = 9.3161$ ($p < 0.000$), with a value of $a = 0.4337$ ($p < 0.000$). As a third step, we tested the regression analysis of the dependent and mediator variables (**I4.0 to SC performance**). This regression analysis was significant, $F = 65.3217$, $t = 9.4948$ ($p < 0.000$), and the b coefficient was 0.4996 ($p < 0.000$). As a final step, we measured the regression analysis before including a mediator and the indirect causality. The results show a diminishment of the direct effect, and the value of c', when I4.0 interacted, was reduced to 0.0347 and is not significant ($p>0.05$). The total effect was 0.2513 ($p<0.005$). Additionally, we measured the mediation strength by calculating the variance accounted for by VAF (a ratio between the indirect effect and the total effect). This value was 86%, indicating a complete mediation effect. Hence, we accept H_6. I4.0 fully mediates the relationship between REC and SC performance.

Moreover, we assume that SC performance (SC perf) can impact a company's performance (PERF) only if REC includes I4.0 and SC. Hence, we tested H7 using a parallel multiple mediation model. We had two mediator variables, one preceding the other (Mediator variable 1: I4.0 → Mediator variable 2: REC). SC performance is the independent variable, and PERF is the dependent variable. In multiple mediator analyses, full Mediation exists if all the indirect effects are positive and significant. Also, the Mediation effect can be assessed by dividing the indirect effect by the total effect; if the result exceeds 80%, then a full mediation is affirmed. Partial Mediation exists if the value ranges between 20% and 80%. Otherwise, no mediation is assumed. Otherwise, no mediation is assumed. Thus, Table VII, shows the results of H_7 testing (see Fig. 1). The parallel multiple mediation model was significant ($F>54$, $t>2.9$, $p<0.001$), indicating generalizability. The coefficient values were: ***a*** = 0.2181 (**SCperf → I4.0**), ***a´*** = 0.3278 (**SCperf → REC**), ***b*** = 0.2143 (**I4.0 → PERF**), ***b´***= 0.1151 (**REC → PERF**), and ***c*** = 0.4244 (**SCperf → PERF**), all measures were significant ($p<0.000$). The ***c´*** value was 0.3148 and remained significant ($p<0.05$). The direct effect (**c**) remained significant ($p < 0.001$) despite the REC-I4.0 interaction; the total effect was 0.4244 ($p<0.005$). (see Table VII)

TABLE VII
PARALLEL MULTIPLE REGRESSION ANALYSIS OUTCOMES

		Coeffic.	R	R-sq	MSE	P
SC->PER	*c*	0.4244	0.5386	0.2901	0.1247	0
SC->REC	*a*	0.2181	0.193	0.0372	0.3481	0.017
SC->I4.0	*a'*	0.3278	0.6175	0.3813	0.1237	0
REC->I4.0	*d*	0.3033	0.6175	0.3813	0.1237	0
SC->PER	*c'*	0.3148	0.6218	0.3866	0.1086	0
REC->PER	*b'*	0.1151	0.6218	0.3866	0.1086	0.004
I.40->PER	*b*	0.2143	0.6218	0.3866	0.1086	0.003
Total effect X->Y		0.4244			0.0412	.0000
Direct effect of X on Y		0.3148			0.0436	.0000
Indirect effect(s) of X on Y:			BootSE	BootLLCI	BootULCI	
Total		.1095	.0281	.0577	.1683	
Ind1		.0251	.0123	.0051	.0528	
Ind2		.0703	.0220	.0295	.1160	
Ind3		.0142	.0067	.0035	.0297	

Based on the analysis of data from Table VII, we reject H_7, because the model tested does not demonstrate full mediation. Instead, there is partial mediation because the direct effect is reduced but remains statistically significant. Also, we estimated the three indirect effects, all of which were positive and significant ($p<0.005$). The total VAF was 26%, confirming partial mediation. VAF values were: Indirect effect (1) = 16%, Indirect effect (2) = 17%, and Indirect effect (3) = 3%. These results are aligned with the literature, indicating that I4.0 complements REC. Also reflects the investment, training, and process adaptation demands associated with implementing I4.0. Moreover, I4.0 and REC partially explain the relationship between SCperf and PERF, primarily because of the moderate level of I4.0 implementation. The companies are more internally connected but lack robust external integration with customers and suppliers, mainly using communication to meet deadlines rather than to integrate their systems.

To test H8, we examined the correlations between variables (see Table III). Values were weak to moderate but significant (0.290 to 0.800; p<0.000), indicating low risk of multicollinearity. Predictor variables were statistically correlated with PERF, justifying the use of multiple linear regression. First, we evaluated a hierarchical regression analysis between REC and SCperformance (independent variable) and PERF (dependent variable) (**Model 1: REC, SCperf → PERF**). Model 1 was significant ($F(2, 307) = 12.343$; $p < .000$), and the R^2 value indicated that REC and SCperf explained 7.4% of the PERF variance. Second, we included I4.0 (**Model 2: REC, SCperf, I4.0 → PERF**). R^2 value increased to 10.0%, indicating I4.0 explained an additional 2.6% of PERF variance ($\triangle R^2 = 0.026$, $F(1, 306)=11.327$; $p<.000$). The predictor variables were statistically significant. I4.0 showing the highest Beta ($\beta=0.186$, $p<.003$), followed by REC ($\beta=0.177$, $p<.005$) and SCperf ($\beta = .167$, $p<.011$). (see Table VIII)

TABLE VIII
HIERARCHICAL REGRESSION ANALYSIS

Factor	PERF	
	Model 1	Model 2
REC	0.173**	0.142**
SCperf	0.200**	0.160**
I4.0		0.168**
F	12.343**	11.327**
R	0.273	0.316
R^2	0.074	0.100
Adjusted R^2	0.068	0.091
VIF	1.004	1.108
Changes in R^2		0.026
Durbin-Watson statistic	1.752	1.752
t-statistic	6.633	5.415

* * p< 0.000, * p<0.0

These previous results confirm that I4.0 makes the most significant contribution to PERF. Therefore, we accept H_8: REC improves SC and Company performance, but performance increases when I4.0 is integrated [18]. I4.0 is a critical paradigm for enhancing SC reconfiguration and performance. The empirical evidence indicates progress in implementing IoT and cloud computing tools, but there are limited advances in CPS technologies, despite their growing impact on performance. (see Table VIII).

V. CONCLUSION

A. Empirical evidence and previous literature

Digital transformation has become imperative over the last two decades. Prior research explores the potential benefits of information and communication technologies for firms and their collaboration with stakeholder [55], but, not all present presents the current level of application of the REC dimension and I4.0, and the impact on SC, SC Performance, and companies' performance. Furthermore, we evaluated how SC and REC can enhance performance when I4.0 is involved and how I4.0 can strengthen SC. We established a framework to define the redesign requirements of REC by considering the current function and effect of each REC dimension, as well as the current level of I4.0 implementation, to choose the best configuration that responds quickly and fits market needs. Results demonstrated that assessing REC and I4.0 is a critical phase that should be applied to improve SC and companies' performance [2]. However, not all companies have the same level of RE application. Empirical evidence indicates a moderate implementation level of the REC dimension, with a performance exceeding four out of five points. From the analysis of each REC dimension, the Modularity dimension scored lowest due to the high investment and effort requirements for SC restructuring. This directly affected the lead time and did not significantly impact costs. In addition, results demonstrated that Companies prefer to implement and strengthen REC dimensions that positively impact SC costs (Customization, Scalability, and Conversion) rather than those focused on restructuring layout, machinery, equipment, and tools. This means companies' REC are more inclined toward cost-reduction dimensions, focusing on flexibility, high reactivity, and reduced SC times. However, evidence supports that the performance of these dimensions is affected by the degree of technological implementation.

Furthermore, we tested fifteen REC enablers. As a result, companies face a moderate degree of readiness for structural changes in supply chains; nine enablers improve REC, while six enablers constrain REC performance due to the low level of I4.0 implementation across these dimensions (Network structure design, Responsiveness, Real-time integration, Transfer pricing, Visibility, and Data reliability). Thus, I4.0 is a critical factor in accelerating and improving all efforts to achieve a reconfigurable supply chain. I4.0 explains at least 3% of PERF variance, directly influencing SC performance. From the parallel multiple mediations model, we found that I4.0 acts transversally across organizations. Its application integrates different areas and articulates all organizational levels. Nonetheless, I4.0 has a moderate degree of impact because not all companies have a high level of I4.0 implementation. The software and systems are often not connected to the SC network, which typically shows a satisfactory level of intra-connection but low external connections, along with limited technology, tools, equipment, and software related to I4.0. Hence, the empirical evidence and model tested align with the literature: I4.0 is a key factor (paradigm) in improving REC. A high level of I4.0 implementation contributes to achieving a high degree of REC, which is a fundamental factor in enhancing SC performance and companies' performance. Furthermore, for managers and decision makers, integrating REC with I4.0 provides preventive, descriptive, diagnostic, predictive, and prescriptive insights, generating input for informed decision-making and optimized operation across each reconfigurability dimension.

Moreover, as the literature suggests, companies with more I4.0 applications have created reconfigurable supply chains. This is corroborated by Ameer and Dahane (2021), who conclude that I4.0 has become an essential enabler of reconfigurability, leading to more responsive systems [54] and increased competitiveness. From the empirical evidence, we can conclude that companies with a high level of I4.0 implementation outperform others because they facilitate communication with customers and suppliers by providing product traceability. Therefore, companies should strive to achieve an intelligent and reconfigurable supply chain (SC) with cost efficiency by implementing elements of resource efficiency (REC). This approach contributes to more flexible and transparent processes both within and outside the company, ultimately improving product quality.

Consequently, the practical implication of this study for businesses and managers is to understand when and over which reconfigurability dimension it is necessary to focus and invest to enhance company performance as quickly as the market and demand require. Additionally, it helps identify which REC enablers companies should prioritize to achieve better performance. At the time, the manager needs to accelerate the inclusion of more technologies along the REC, as this accounts for almost 50% of their performance. Also, managers and decision makers can prioritize real-time integration and visibility by adopting IoT-enabled sensors to monitor production lines, ensuring rapid response to demand fluctuations. In contrast, service-oriented industries, such as logistics, may benefit more from focusing on responsiveness and data reliability to streamline delivery processes and enhance customer satisfaction. Managers can leverage predictive analytics from I4.0 to anticipate supply chain disruptions, tailoring REC strategies to specific operational needs. Hence, I4.0 can easily monitor, evaluate and enhance interactions with the market by implementing agile business techniques [56]. For example, implementing cloud-based platforms can improve data sharing across supply chain partners, enhancing traceability in industries like food and beverage, where regulatory compliance is critical [57].

Finally, managers and decision makers can recognize that investing in REC enablers not only supports internal processes but also enhances traceability and active customer participation along the SC, tailoring the process to their needs and boosting company performance. Therefore, this paper provides managers with a framework or context to analyze and collaborate on creating a strategy to enhance progressive SC, REC, and I4.0 in companies.

B. *Limitations and future research*

This paper presents an empirical analysis of companies in the context of high-performance manufacturing practices in 14 countries. We evaluated the construct based on responses from three specific sectors, which limits the generalizability of the findings to other industrial sectors or regions. This is due to the varying levels of resources and available technologies that help reconfigure and accelerate companies' supply chains. For example, the effects of REC and I4.0 may vary significantly between sectors like the automotive industry, where high capital investment in automation is common, and the textile industry, where smaller-scale operations may face resource constraints. Similarly, regional differences, such as advanced technological infrastructure in developed economies versus limited digital connectivity in developing regions, can influence the adoption and impact of I4.0 on REC performance. These variations suggest that sector-specific and region-specific factors, such as market dynamics, labor costs, and regulatory environments, may alter the effectiveness of the proposed framework. Assessing the construct holistically, without evaluating the contribution of each element within the scales to the overall performance of the models (such as using observable variables rather than latent variables), presents challenges in disaggregating the analysis. This makes it difficult to identify which specific practices, tools, or methodologies are most effective in enabling or enhancing supply chain (SC) performance, or which factors may limit the success of reconfigurable supply chains (REC), Industry 4.0 (I4.0), and overall SC performance. Future research could address these limitations by conducting comparative studies across diverse sectors, such as services or retail, and regions with varying levels of technological maturity to identify sector-specific and region-specific drivers and barriers to REC and I4.0 implementation.

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