Determinants of computer vision system's technology acceptance to improve incoming cargo receiving at Eastern European and Central Asian transportation companies' warehouses. Mixed methods pilot study

Askar Aituov, Ramesh Kini

***Abstract* — Transportation companies' warehouses are an integral component of the global supply chain. However, SMBs have limited technology awareness to assess the impact of digitization on certain processes. In particular, the incoming cargo receiving process at transportation companies worldwide has a substantial fraction of manual labor. In this study, we focus on the cargo dimensioning process of LTL and retail companies' warehouses in Poland, Estonia, Belarus Republic, and Kazakhstan and identify whether computer vision dimensioning system usage has a positive effect on warehouse performance and its adoption determinants.**

Combining data from 20 expert interviews, literature review, and quantitative process mining experiments with computer vision dimensioning system performing daily dimensions within 6 months, we conclude that system reliability might be an additional acceptance determinant, which has an influence on Perceived Usefulness. Next, based on the process mining experiments we conclude that the computer vision system is capable to increase information flow in control conditions forty times and four times in the experiment condition. Finally, we find that increase in dimensioning speed as a result of IT system implementation could not be used to assess the impact on the material flow at LTL transportation company but could be a valuable source of data for the capacity monitoring process.

***Keywords* — Digital supply chain, technology acceptance model, process mining, IS value, computer vision**

I. Introduction

Transportation industry includes a number of participants: freight brokers, carriers and shippers. As has been previously reported in the literature, pandemic impacted global transportation industry unlike any occurrence seen in recent times [1]. For instance, due to COVID 19, number global maritime shipments decreased to 20 percent in Q1 2020 compared to the same period in 2021 [2]. Thus, the value of Information Systems for restoring viability and resilience of global supply chain is increasing [3].

Issues of inefficiency and transaction costs in transportation industry arise regularly. Prior research reveals that high competition in transportation industry discourages information sharing and leads to lack of real time data on demand forecasting, trucks availability, cargo volume and dimensions [4]–[6]. On the other hand, large transportation companies such as Fedex and Amazon are increasing their technology infrastructure, while medium and small sized transportation companies face limitations of IT budget, talents, knowledge and technology awareness [7]–[9].

Whilst, transportation companies which do not invest in machine learning and big data – are outperformed by competitors, occasionally arising issue is how to maximize return on digital investments, assess impact of IT value, before committing investments [10], [11]. Especially for warehousing processes, certain IT system's benefits are unobvious on small transaction volumes. Although, information systems enable reduction of manual work, empirical data from prior research does not reveal productivity gains despite investments to information technologies [12]. Empirical research data on predicting IT value and performance effects for warehouses are few. In contrary, large investments into IT systems might disrupt current operations [13]. On the other hand, process management professionals admit that business process changes should be embedded in the software [14].

We identified lack of empirical studies on implementation of computer vision based IS for transportation companies warehouses. In particular, incoming cargo receiving process at transportation companies is typically out of scope of industrial warehouse management systems (WMS) and it is difficult to calculate its ROI. [15]. As prior research pointed out, warehouse related costs constitute one fourth of transportation related costs [16]. Upon arrival of cargo, each warehouse has mandatory procedure for receiving incoming cargo. Speed of cargo receiving is affecting shipments volume, which is an important data for demand forecasting [17]. Receiving process includes cargo unloading from transport, measuring and recording its dimensions, labeling and putting to the storage area [5], [18]. Figure 1 describes typical cargo receiving procedure, which corresponds to Supply Chain Operations Reference (SCOR) models' RS.1.1 - Order Fulfillment Cycle Time metric.

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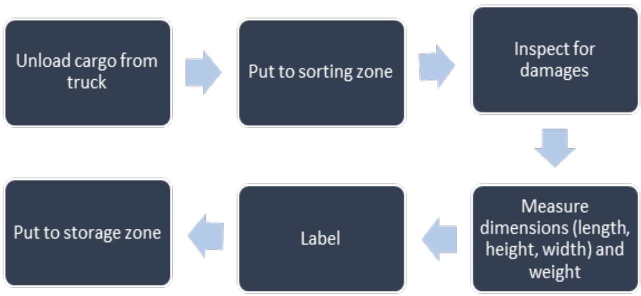


Fig. 1. Typical cargo receiving process at the warehouse, which corresponds to SCOR's RS.1.1 - Order Fulfillment Cycle Time metric. Developed by Authors.

In this regard, the objective of this work is to identify whether computer vision dimensioning system usage has positive effect on warehouse performance. The study also investigates computer vision based dimensioning system's adoption determinants and ways to assess economic effect from IT system, since assessing the effects from IT investments remains a serious concern for middle-sized transportation companies.

The study is significant because performance of cargo receiving process is a foundation for transportation companies billing process in any country. While there is lack of methodology to assess impact from IS investment into the cargo receiving process and to ensure sustainable improvement in business processes. Firstly, this works empirically tests effects on information system on cargo receiving process performance. Secondly, the study informs warehouse management how to assess IT value prior committing investments. The research can also contribute to investigation of digital twins for supply chain.

Combining data from 20 expert interviews from Kazakhstan, Poland, Estonia and Belarus Republic and literature review we conclude that system reliability might be an additional determinant, which has influence on Perceived Usefulness within Technology Acceptance Model. Next, based on control and experiment conditions performed with 10 000 transactions at warehouse's production environment we conclude that computer vision system is capable to increase information flow in control condition forty times and four times in experiment condition at production environment. Finally, we find that, increase of dimensioning speed because of IT system implementation could not be used to assess impact on material flow at LTL transportation company, but could be valuable source of data for capacity monitoring process.

II. Literature review

This section outlines theories that describe business value of information systems, technology acceptance model's determinants of technology adoption and transportation companies' performance metrics such as SCOR model.

2.1 Impact of Information Systems on supply chain performance

Researchers draw attention to shifting role of information systems from supporter of business processes to becoming key enabler of value exchange between supply chain participants [19], [20]. Accordingly, logistics industry is in transition to applying digital technologies to the key components of supply chain such as transportation, warehousing and business processes such as real time digital supply chain modelling, fleet matching [21], [22].

During first wave of 2020 Pandemic, retail and logistics supply chains demand forecasting systems in certain industries became ineffective, while transparent information sharing with centralized information collecting and communication across supply chains emerged as an effective strategy for solving bottleneck problems and demand fluctuations [23]. In 2020, Karahanna reported applications such as robotics delivery of care to patients could be one of the non-pharmaceutical interventions pillars to fight COVID 19. Multinational technology companies demonstrate how agile digital supply chains can predict and respond to rapid changes in demand forecasting and infrastructure monitoring [24]. Example use case of multinational companies' IT solutions is engine sensors which are combined with GPS-verifiable data to create an automated fuel tax reporting system that allows logistics companies in the supply chain to optimize gas consumption for their delivery fleets [25]. Studies carried out during the 2020 Pandemic indicate that warehouse performance was often the bottleneck [3], [23].

Notwithstanding that, introduction of new technologies is a high risk activity with high failure rates regardless of the systems architecture: centralized, cloud or serveries [26]. Respectively, middle sized transportation companies' IT departments face pressure to adapt to quickly changing business demands and maintain IT services reliability and uptime [27]. Traditionally software development teams and IT operations teams work on different methodologies and workflows, for instance ITIL, DevOps for operations and Agile for development [27]. Since, majority of small and medium sized transportation companies cannot afford expensive software developers, transportation companies IT capabilities are supported by IT operations specialists who implement third party or open source software [28].

With implementing third party software, which is not developed internally, transportation companies face the challenge of technology acceptance to ensure positive impact of business processes digitization [29]. As prior research suggests, even if organizations implement IT systems successfully, those systems are seldom used [30]. In order to decrease cases of this sort, studies of human computer interaction led to creation of technology acceptance model (TAM) which is applied for predicting technology acceptance across industries.

Prior studies in supply chain digitization of logistics place attention on criterions for technology adoption and effects of usage to but overlooking determinants of TAM for computer vision adoption [4], [21], [22], [31]–[33]. While, transportation companies warehouses seem to be a domain which could benefit from digitization, as the typical warehouse's largest operating expenses are labor costs, constitute up to 70 percent of the average company's warehousing budget [34]. Since the issue of assessing effects from IT system usage includes technology adoption criterions, this study focuses on factors, which drive usage and impact from usage.

2.2 Technology acceptance model and determinants of technology adoption for transportation companies

TAM could be useful to assess factors, which drive adoption for computer vision system for cargo receiving process. TAM is extensively applied by number of academics and practitioners during development and implementation of IT systems [35], [36]. TAM states that perceived ease of use is a key driver of user acceptance and usage of information technologies (Venkatesh, 2000). Perceived usefulness is influenced by perceived ease of use, as the easier technology to use, the more useful it can be [30]. Perceived ease of use has its determinants such as usability, perception of control and others [30].

Next, by integrating TAM and seven other established user acceptance models a Unified Theory of Acceptance and Use of Technology was formulated (UTAUT). UTAUT highlighted the significance of four determinants performance expectancy, effort expectancy, social influence, and facilitating condition [37]. These determinants are impacted by users age, gender, experience and voluntariness of use [37]. Further research revealed how managers in organization can increase acceptance and greater utilization of IT. It is indicated that managers at organizations should form adequate perception of IT system's characteristics during pre-implementation phase and provide training, organizational support infrastructure at post implementation phase [38].

Still, other research has focused on integrating TAM with trust theories for shedding the light to social mechanisms of E-commerce applications acceptance [39]. However, there is lack of research focused on evaluating determinants of technology adoption within transportation companies' context. We hypothesize that there are additional determinants of PU for the context of incoming cargo receiving process at the warehouse.

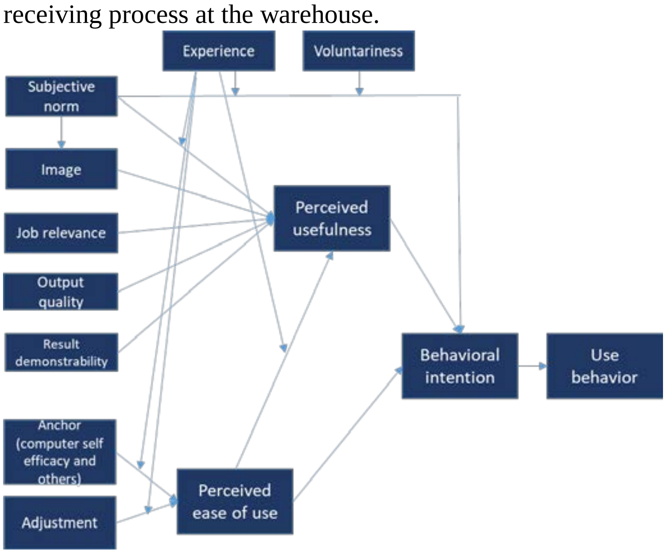


Fig. 2. TAM3. Source: Venkatesh and Bala 2008.

2.3 IT value and performance for supply chain

Impact of information system usage is assessed via a number of school of thoughts which could be considered via two groups: assessment of direct financial value assessment of impact on business performance.

2.3.1 Direct financial value

Total cost of ownership, economic value added and total economic impact are financial metrics for controlling IT spending, but does not provide complete view on IT systems performance [40]. Total value opportunity, is updated version of total cost of ownership metric, which provides projections of IT investments to the business value metrics [41]. It is difficult to calculate IT value of computer vision implementation with financial metrics without using other types of intermediate metrics.

2.3.2 Measuring IT impact on business performance

Prior studies suggest that existing measures at organizations (e.g., ROI or cost savings) cannot adequately capture the business value from digitization, making it necessary to explore other measures of IT value [42].

Common effect of automation is decreased transaction costs across the supply chain [6]. [24] found that effect from digitization of supply chain between different organizations could be captured with value metric - share of wallet and buyer loyalty. Other supply chain studies suggest to identify effectiveness of IT investment via measuring interfirm IT capabilities [43]. [44]also advocated to use methods based on measuring value in relation to business process performance.

Research of [33] crosschecked transportation companies' IT system logs and financial performance, established that integrated group of information systems yield performance gains in the form of information, physical and financial flow inside the organization and between other parties. However, the case of a standalone IT system's performance gains at the warehouse context was not reported.

Prior research highlights that decision support systems in the form of digital twins and warehouse management systems (WMS) positively influence the speed of problem identification and quality of operational decision making at the warehouse [5], [20], [45]. However, quantifying return on investments into WMS could be problematic because information on inventory is available only partially i.e., volume, weight [5]. Availability of this information is dependent from the incoming cargo receiving process.

Prior research on digitization performance impact within warehouse context cover information flow between warehouse and other components of supply chain, but does not consider in detail the process of incoming cargo receiving [5], [46], [47].

Supply chain performance metrics which are connected to warehouse and delivery performance are indicated in the supply chain operations reference model [18], [47], [48].

2.3.3 SCOR model

SCOR supply chain model points at receiving and verifying the product as one of the key operations with stocked products at the warehouses, which is recorded via decrease of order processing time by the following metric - RS.3.102 - Receive & Verify Product by Order fulfillment Cycle Time [18].

Other studies indicated that cargo receiving is a substantial part of warehouse processes [49]. Warehouses could be classified into various types, such as production warehouses, finished good warehouses, distribution centers, fulfillment warehouses [49], [50].

Table 1. Provides synopsis of key concepts for assessing IT value for the supply chain.

Table 1. Key concepts for assessing IS value. Developed by Authors.

#	Metric	Scholar
1	Buyer loyalty	Rai et al., 2012
2	Increased information/finance/material flow	Rai et al., 2006
3	RS.3.102 - Receive & Verify Product by Order fulfillment Cycle Time	Baruffaldi et al., 2019; Jamehshooran, et al., 2015; K 2005; Kim et al., 2020
4	Share of wallet	Rai et al., 2012
5	Total cost of ownership	Mayor, 2002
6	Total economic impact	Mayor, 2002
7	Total value opportunity approach	Apfel & Smith, 2003
8	Decreased transaction cost	Hobbs, 1996

Authors hypothesize that usage of standalone computer vision system for cargo receiving process can be directly translated into increased speed of information/material/financial flow. And automating incoming cargo receiving process is decreasing order fulfilment lifecycle time.

2.4 Research gap and research hypothesizes

The literature review indicated lack of thorough studies on the impact of computer vision system on incoming cargo receiving process at the transportation company warehouse. Moreover, the literature did not present significant concern on the application of TAM and measuring performance impact from automating the cargo receiving process. Therefore, the objective of our research is to examine TAM and identify IT value metric in the context of implementing computer vision system at the transportation company warehouse.

Based on the literature review, in this study we integrated TAM and IT value models to conceptual framework. Authors derive three hypotheses:

- *H1 In the context of transportation company warehouse TAM has an additional determinant which have a crucial impact on Perceived Usefulness*
- *H2 IT value metric #1 - Usage of standalone computer vision system for cargo receiving process can be directly translated into increased speed of information flow*
- *H3 IT value metric #2 – Increased speed of information flow results in increased speed of material flow, and decreased order fulfilment lifecycle time.*

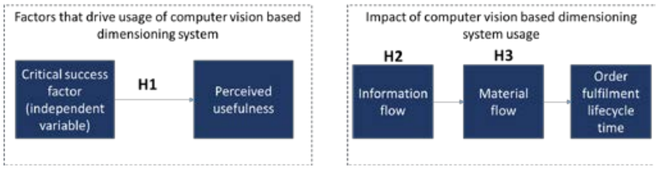


Fig. 3. Conceptual framework. Developed by Authors from literature review

III. Methods

3.1 Mixed methods data collection methods description

Given a limited availability of prior research in the context of implementing computer vision system at the transportation company cargo handling process we use mixed methods approach. Initially we gathered data on TAM determinants via expert interviews. Then, authors incorporated previously unknown determinants into the research model using inductive approach. After that, conceptual model with extended TAM and IT value metrics was tested via quantitative experiment – computer vision system operation in production environment with 10 000 transactions occurred within 6 months period, as suggested by [51]. This was followed by analysis of IT system logs. Based on a deductive reasoning, triangulation of quantitative experiment and qualitative interview results are applied to validate the conceptual model as suggested by prior studies on research design [52], [53]. Finally, authors returned with return to literature review in order to test conclusions against the literature via inductive analysis.

Authors collected the results in person during 8 month of data collection period.

3.2.1. Interviews

Authors applied grounded theory method for qualitative part of the study. During the interviews we identified concepts and coded them. Afterwards, the coded concepts were grouped. We identified that certain coded groups were repeatedly identified by several organizations. While, comparing coded concepts with TAM model and IT infrastructure for supply chain identified by prior research, we asked ourselves: “How these coded concepts are different”.

An integrated approach with mixed coding methods was used. We used deductive method, with known codes from prior literature review and inductive grounded theory method, looking to create new codes by analyzing line-by-line interview transcripts. After interviews, we indexed (codified) transcripts. Then we grouped codes to broader themes and searched for correlations and links. This approach was validated by earlier researchers [54].

20 interviewees were selected from Poland, Kazakhstan, Estonia and Belarus Republic. All interviewees were CEOs, warehouse managers, IT managers from LTL (less than truck load) type transportation companies. All interviewees were males, in the age group between 26 and 52 years old.

LTL type of transportation company was chosen, because this type of companies typically don’t have automated robots at the warehouses and load cargo item by item and measure its dimensions manually. Thus, there is opportunity to automate manual labor of cargo dimensioning with computer vision system.

Table 2. Data sources and geographies. Developed by Authors.

Data source	Data collection type	Number of samples/interviews	Geography
Transportation company warehouse managers and workers	Interview	16	Kazakhstan. Estonia, Poland
Airport transportation department manager	Interview	1	Kazakhstan
Retail company transportation department/warehouse managers	Interview	3	Kazakhstan, Belarus Republic
Transportation companies	Survey	15	Kazakhstan
Computer vision based dimensioning system operations	Observation	6 month period	Kazakhstan
Computer vision based dimensioning system system logs	Review of logs (raw data)	6 months period	Kazakhstan

Survey was used for preliminary collection of context information on what areas are subject to digitization during literature review phase. Then, we derived then known codes related to TAM. Known codes are summarized in Table 3.

Table 3. Known codes from literature review related to TAM. Developed by authors from the literature review.

Perceived ease of use determinants	***Perceived usefulness determinants***
Computer self-efficacy – *anchor*	Result demonstrability
Perceptions of external control – *anchor*	Output quality
Computer anxiety – *anchor*	Job relevance
Computer playfulness – *anchor*	Image
Perceived enjoyment - *anchor*	Subjective norm
Objective usability – *adjustment*	Experience
Trust	Voluntariness

3.2.2. Process mining. Control condition

Experiment site – distribution warehouse of the international LTL transportation company headquartered in Kazakhstan. The transportation company is shipping cargo internationally and locally. Test site was international transportation company's warehouse with 20 000 square meters capacity. Warehouse operates mostly with large stream non-palletized cargo. Daily cargo flow is 2000 items, monthly cargo flow is 50 000 items.

We developed computer vision based dimensioning system and installed it on live production environment at the transportation company's warehouse. The dimensioning information system includes hardware and software components: IntelRealsense depth camera, computer vision software and mini PC (Hereinafter – the System), as illustrated in Figure 4.

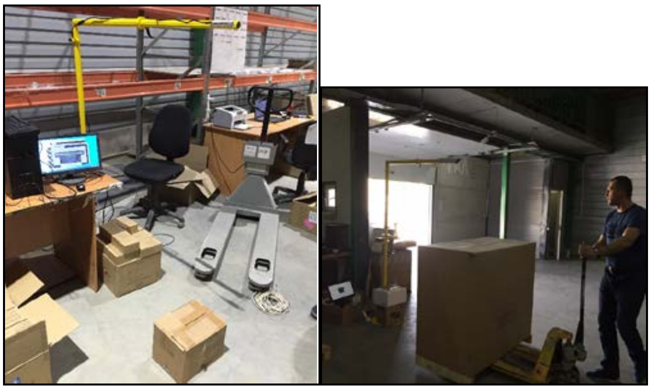


Fig. 4. Picture of the System at the warehouse. Source: Authors own elaboration.

System receives a command to measure from portable handled device or from GUI interface and sending back the results, as illustrated in Figure 5 and 6. The company provides JSON API for integration with warehouse accounting/WMS systems.

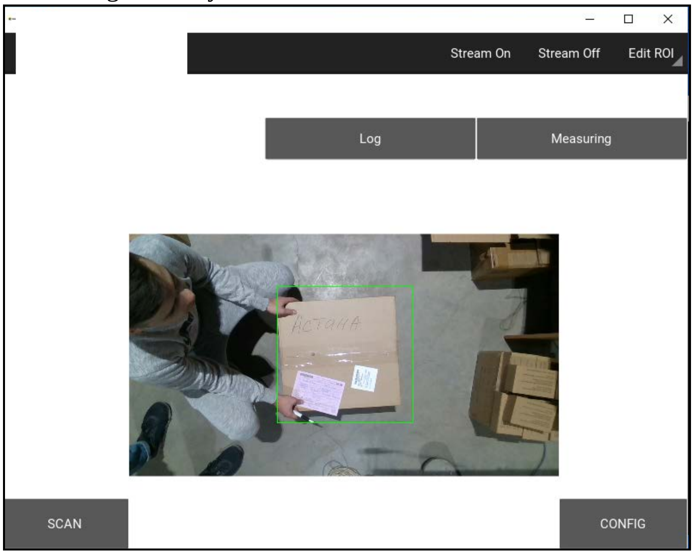


Fig. 5. System's GUI. Source: Authors own elaboration.

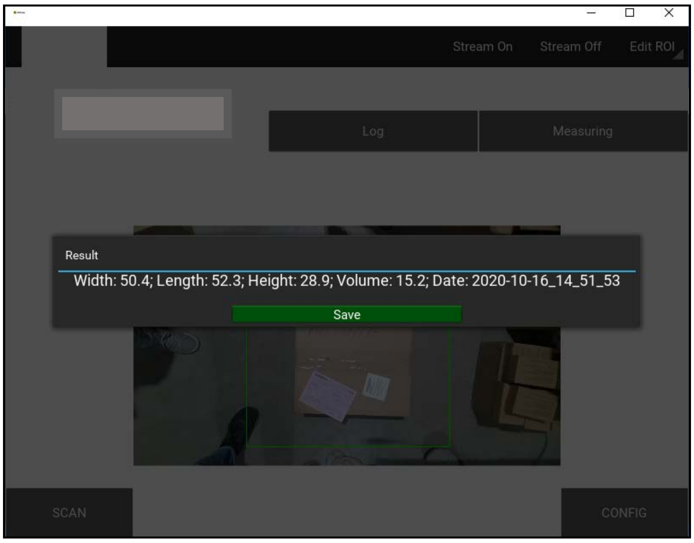


Fig. 6. Dimensioning results. Source: Authors own elaboration.

Computer vision system required calibration to compare calculated dimensions with real dimensions for from July 2020 until middle of August. Because the range of cargo measured was broad, the outcome of comparison during this period resulted in dimensioning errors which exceed KPI – error rate more than 2 cm. During this period the system was adjusted to decrease error rate until the level required by KPI.

Since middle of August, the system achieved production ready state and authors transited the System to the experiment condition at production environment.

3.2.3. Process mining. Experiment condition

Authors implemented dimensioning system at the test environment of transportation company's warehouse in July 2020. The company used the system in daily operational activity of cargo receiving for 6 months since July 2020 until February 2021. Authors then applied process mining methodology which was validated by [55]. An experiment population is all cargo which goes through the transportation company warehouse, limited by length from 20 cm till 110 cm. Limitation is due to physical restrictions of computer vision dimensioning system precision which was identified at control condition. Research sample was random 10 000 cargo items, which constitutes 3,3% of all cargo of 20-160 cm height which went through the warehouse in the 6 months time period.

After 6 months operations authors extracted the system log records in the following JSON format:

(4196, 58.75, 71.04, 15.04, 12.556, '2020-09-07T23:27:51', 1, 'snapphoto'),

(4197, 33.25, 83.81, 54.37, 30.3052, '2020-09-07T23:28:27', 1, 'snapphoto'),

Extracted JSON data stores dimensions of the cargo calculated by computer vision system: ID, length, width, height, volume, transaction timestamp, photo.

Timestamp indicated time intervals between measurement operations. Everyday there was a timestamp for more than one hour difference. This meant that workers shift changed, or cargo batch was ended and workers were idle.

To understand whether there was increase in information flow, we calculated an average difference between successive timestamps. Authors excluded measurement intervals for more than one hour. Because large intervals occurred as a result of intervals between cargo batch deliveries. In order to ensure measurement quality, authors monitored error rates, because in production environment the System encountered new types of cargo for which it was not calibrated.

IV. FINDINGS AND DISCUSSION

4.1 Expert interviews

Twenty warehouse managers from four countries were interviewed. Extracts from the interviews indicate that seven managers explicitly indicated fault tolerance to be crucial criterion for decision whether to implement System or not. Because at the warehouse environment hardware is breaking often due to the following reasons: workers break equipment, dust and humidity decreases equipment longevity.

1. FTL transportation company's IT manager: Workers are unreliable. And often break technique. If camera will be mounted – it should be not lower than 2 meters, otherwise workers will break it (personal communication, March 9, 2020).

2.“We will break this one easily” – said warehouse plant manager when he saw depth camera (personal communication, March 10, 2020).

3. LTL transportation company's CEO: IT system must be damage proof. I won't be surprised if our regular fellows (workers). will break the camera even it will be covered with metal (personal communication, March 15, 2020).

4. Pharmaceutical company's CEO: Our staff at warehouse is uneducated. And often illiterate. They break things. They are unfocused. Can't properly read medical pills prescriptions. Things went better when we banned use of mobile phones. And provided portable terminals which are attached to people's hand (like an iphone for jogging) (personal communication, March 20, 2020).

5. LTL transportation company's IT specialist: We use always outdated PCs and tables because they break in 6 month in average at our warehouse (personal communication, April 2, 2020).

6. Two Belarus Republic's retailers wre focused on efficiency and availability of the system: All workers use special protection mechanisms. Incidents sometimes happen, since we load heavy electronics and KPI for incoming cargo acceptance is 15 minutes. The system must be protected (personal communication, May 5, 2020).

7. LTL company's IT manager inquired what it the procedure for implementation and demanded it to be destruction proof (personal communication, May 15, 2020).

Saturation was reached after 20 interviews.

Three interview respondents indicated that cargo receiving process is a bottleneck, and computer vision based dimensioning system potentially could be used for capacity monitoring and increase (personal communication, May 25, 2020).

Thus, seven experts indicated fault tolerance as critical for computer vision adoption. After expert interviews, we performed additional literature review and revealed system reliability to be the most common term for fault tolerance. Reliability is an ability of a system to provide stable service without failure for a given period of time [44], [56].

The sample of 20 interviewees, was focused on population of 4 countries, all respondents were men and LTL company representatives. Since saturation was reached, authors consider the sample to be valid for a pilot study.

Warehouse worker's low education level was pointed as main factor which bears high risk of equipment failure. This coresponds with earlier studyes which state that human operators could be producers of system failure [57]. Prior studies of TAM extension suggest IT system's quality and again reliability have positive impact on PU in the context of medical industry [36], [58]–[60]. Studies on supply chain resilience revealed that fault tolerance is one of prerequisites for supply chain reliability, since failure in one point of the chain can impact all participants [61]. However not there is lack of standards for fault tolerance in supply chain [62].

4.2 Process mining. Control condition

In a control condition, two warehouse workers were withdrawn from operational activity and were dedicated to perform the tests. During the test, workers compared speed of dimensioning operation performed in two ways. First, manually with tape. Second, automatically via computer vision system. We measured twenty three cargo items with different shape.

Results of the measurement are following. Manual method allowed one measurement per forty seconds. While, computer vision system allowed one measurement per one second, which is forty times increase in information flow. However, with time required to pick and move a box total time for measurement was ten seconds.

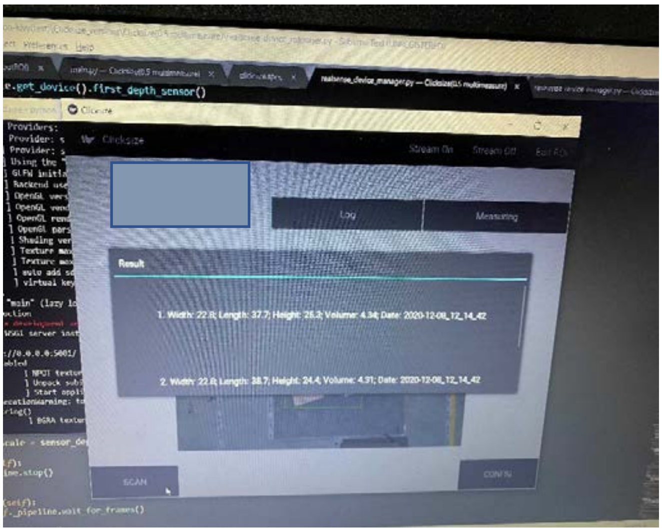


Fig. 7. Experiment. Control condition - comparing manual and automated dimensioning impact on information flow and material flow. Source: Authors own elaboration.

For the experiment, authors agreed on SLA with Transportation Company and set KPI for error rate in computer vision dimensioning calculations to be no more than two centimeter difference from actual dimensions.

Out of twenty-three objects, one object with length of 117 cm was measured incorrectly, due physical restrictions of camera's field of view, as indicated in Table 4. In order to ensure experiment validity, authors decided to exclude cargo with more than 110 cm length from the experiment condition.

Table 4 Control condition with two dedicated workers withdrawn from operational activity: computer vision based dimensioning versus manual tape based dimensioning. Source: Authors own elaboration.

Information			Measurements						Errors		
			Real			Computed			Metric		
	Device	Object Name	L	W	H	L	W	H	L	W	H
Average interval between measurements - 10 seconds	Intel realsense D435 depth camera	Medium Box	44	31	53	44.7	31.8	51.3	0.7	0.8	1.7
		Long box	89	45	15	89.4	43.3	15.2	0.4	1.7	0.2
		punching bag	75	30	26	75.4	28	24.5	0.4	2	1.5
		Long box	117	33	20	106	30.6	20	11	2.4	0
		Microwave(box)	51	45	34	52.5	43.7	33.7	1.5	1.3	0.3
		Microwave(box) inverted position	45	34	51	43	35	51.6	2	1	0.6
		TV(box)	83	50	13	83.7	49.6	13.8	0.7	0.4	0.8
		black-white box	54	33	8	54.3	33.9	7.6	0.3	0.9	0.4
		TV with stand(Lying position)	50	50	17	51.6	49.1	16.5	1.6	0.9	0.5
		Small white box	26	25	15	26.5	23.8	13.4	0.5	1.2	1.6
		Small box	30.5	27	18	31.4	26	17.6	0.9	1	0.4
		black-white small box	25	19	9	26.8	19.9	7.2	1.8	0.9	1.8
		White medium box	40	25	18	41.1	24.8	17.6	1.1	0.2	0.4
		Big box	58	31	60	69	31	58	1	0	2
		Backpack	43	35	7	43	34.2	7.6	0	0.8	0.6
		LEGO toy (box)	52	31	7	53	31	7	1	0	0
		small box	36	19	9	36	19	9.2	0	0	0.2
		white small box	30	20	12	31.8	20	12.4	1.8	0	0.4
		black-white box	24	22	18	24	23	18.7	0	1	0.7
		Cutting board white top	32	32	4	31	31	4.5	1	1	0.5

In a control environment an effect from computer vision based dimensioning system is represented as forty times increase in information flow, but only four times increase in material flow. Thus, in a control environment usage of IT system results in increased speed of information and material flow. Effect on order fulfilment cycle was not measured at control environment.

4.3 Experiment condition

At the experiment condition in 6 months period, an average time between transactions ranged from one minute thirty seconds to two minutes and fifty seconds. We also measured time intervals for non-stop measurement of cargo batches. This indicator varied from eighteen seconds in August, to two minutes in January 2021. Only August and September measurements showed increased speed of measurement, eighteen seconds and forty seconds correspondingly compared to average two minutes in other months.

August, September and October are months when system was operating at full scale. In the middle of October, under external impact of dirt and workers operations System's camera was displaced. As a result, System 30% of cargo dimensions operations in October were erroneous, with errors exceeding 2 cm SLA level. Figure 8 illustrates camera displacement which led to calculation errors.

By November, the faulty hardware component was replaced, but the workers abandoned the system and were not willing to start using it again.

Fig. 8. a. On the left - correct camera angular which leads to correct calculations. b. On the right - displaced camera angle since October 2020 that led to exceeding 2 cm SLA error rate. Source: Authors own elaboration.

In January 2021, warehouse manager and worker's supervisors decided to implement the system again in multiple sites in order to monitor performance of workers (personal communication, January 03, 2021).

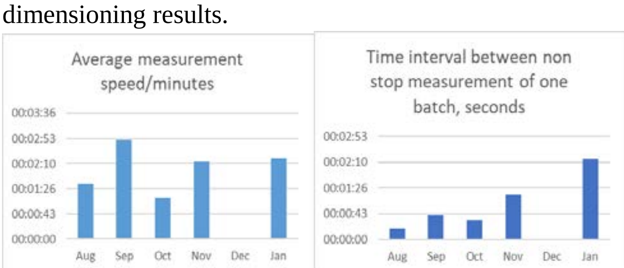
Results of the System's operation at the warehouse indicated in Table 5.

Table 5. Results of the System's operation at the warehouse production environment. Source: Authors own elaboration.

Period	Average measurement speed/minutes	Non-stop measurement within single cargo batch speed/minutes	Number of transactions	Correct calculations of same type of cargo
July	0:01:58	*computer vision system alignment period at the test environment*	418	0,8
Aug	0:01:35	*transition to the production environment* 0:00:18	2440	0,99
Sep	0:02:51	0:00:40	4616	0,99
Oct	0:01:11	0:00:32 hardware fault emerged	890	0,8
Nov	0:02:13	0:01:15	44	0,7
Dec	System abandoned by workers	n/a	0	n/a
Jan 2021	0:02:20	0:02:15	35	0,99

The graph shows the dynamics of dimensioning operations. At first month of computer vision system's operation time interval between non-stop measurement had the smallest value of eighteen seconds. This was followed by gradual increase of the interval each month to two minutes in January 2021.

See table 5. Results of System's operation at the warehouse and Figure 9. Experiment condition - 6 months dimensioning results.



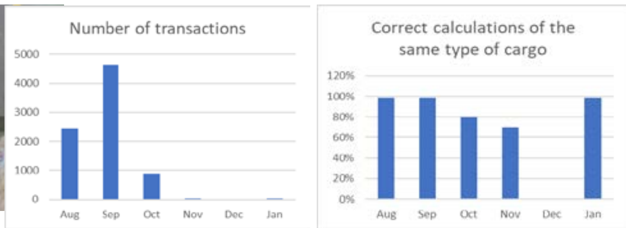


Fig. 9. Process mining. Experiment condition - 6 months dimensioning results. Source: Authors own elaboration.

Average measurement speed increased steadily over first three months of operation, but it never below one minute and ten seconds. Experiment condition average speed is 40% slower compared to control condition average speed – forty seconds. Fluctuation from control condition is considerable. From our observation and discussion with warehouse managers, reasons for variance in production environment are: a) large batches of cargo - 500 items in one batch in average; b) workers turnover - more than 6 workers operated the System within 6 month period; c) absence of strict KPIs for cargo receiving process at the experiment site warehouse.

The experiment condition at production environment showed, that increase of information flow does not affect speed of material flow or order fulfilment time.

Workers indicated the limitation of experiment. After the experiment workers said that measuring large cargo batches one by one is annoying because the System requires to put cargo on the scales-platform beneath the camera one by one (personal communication, November 25, 2020). In contrary, manual dimensioning allowed to cover several items with a single tape.

Absence of workers KPI for cargo receiving time was a limitation as well. Authors revealed during the experiment with 10 000 transactions, despite manager's aspirations, speed was not a priority for workers. The key priority was decreasing erroneous measurement of manual method.

V. CONCLUSIONS AND IMPLICATIONS

5.1 Conclusions about research hypothesizes

H1 In the context of transportation company warehouse TAM has an additional determinant which have a crucial impact on Perceived Usefulness – confirmed

Combining data from 20 expert interviews from Kazakhstan, Poland, Estonia and Belarus Republic and literature review we conclude that system reliability is most common term used in prior research for naming fault tolerance. System reliability can have a positive impact on PU. Moreover, during the experiment condition system availability temporary decreased below SLA level and workers immediately abandoned the system. Afterwards, when system availability level restored, workers were reluctant to return to System usage immediately. Based on the analysis we conclude that system reliability could be determinant of technology acceptance for computer vision based systems at LTL transportation companies. Although no TAM studies in transportation companies context were identified, these findings concur with results of TAM studies in medical industry context, [36], [58], [59].

Consequently, in the context of transportation companies TAM might have an additional determinant – system availability which has influence on Perceived Usefulness.

H2 IT value metric #1 - Usage of standalone computer vision system for cargo receiving process can be directly translated into increased speed of information flow - confirmed

Based on process mining control and experiment conditions performed with 10 000 transactions in the period of August, September and October month we conclude that computer vision system is capable to increase information flow in control condition forty times and four times in experiment condition at production environment. This result endures Rai, Patnayakuni, and Seth (2006)'s framework of IT systems' impact information and material flow increase, and makes it more specific for the context of transportation companies.

H3 IT value metric #2 – Increased speed of information flow results in increased speed of material flow, and decreased order fulfilment lifecycle time – not confirmed

Experiment results indicated that even though computer vision dimensioning system increased information flow at the warehouse, material flow did not increase. In January 2021, on the last days of experiment, the transportation company management decided to use the computer vision system for capacity monitoring and establishing baseline for future bottleneck improvements (personal communication, January 8, 2021). Thus, increase of dimensioning speed because of IT system implementation could not be used to assess impact on material flow at LTL transportation company, but could be valuable source of data for capacity monitoring process. Lodmark (2021) also argues that optimization of warehouse operations should be started with capacity measurement of incoming operations by obtaining medians of time available/time spent completing the task.

This is consistent with prior researchers who argues that supply chain's performance is increased if integrated IT infrastructure across supply chain participant, not limited to digitization of a single process [24], [42].

5.2 Theoretical implications

The pilot study research findings complement technology acceptance model, in view of the fact that TAM is applied to LTL transportation companies' context and additional PU determinant – system reliability is recommended for inclusion to TAM.

Moreover, we contribute to IS value research which is concerned with the question "Under what conditions investments to IS pay off" [64], [42], [65]. This study provides empirical framework for translating effects from cargo dimensioning automation into increased information flow.

5.3 Practical implications

The work have shown how process mining techniques could be applied to empirically measure IT value. Although information flow is increased, the material flow could not be measured directly, even if information flow is increased in the context of LTL company's cargo receiving process. This could be useful for warehouse managers, transportation company executives, and CIO's identifying cargo dimensions is a base metric for further calculations capacity and warehouse processes efficiency. Since, eventually financial success of transportation company is correlated with ability to increase cargo processing time with people, infrastructure and equipment [66]. Moreover, in large warehouses each step and each dimensioning transaction costs money. Calculation of whether computer vision will increase speed of information/material flow also depends whether there are KPIs for monitoring speed of cargo handling in place.

Another implication for warehouse IT managers, is that system reliability is crucial for technology adoption in the warehouse. However, depending on the method incoming cargo receiving, the process can be considerably different, and framework should be adapted accordingly.

5.4 Limitations and future research directions

This empirical studies data sources – limited to LTL transportation companies, and certain retailers. Other types of warehouses were not considered. Warehouses share similar pattern of operations, but depending certain business processes can differ.

Authors have not measured overall cargo processing lifecycle, but a dimensioning process, thus effect of overall cargo processing lifecycle was out of study's scope.

The pilot study's outcomes might be used as a part of larger research of digital twins performance in supply chain, since digital twin is a model that can represent the state of supply chain [31]. Another are for further research is investigation of effects from decreasing error rates as a result of computer vision adoption within the IS value studies.

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APPENDIX

Example of questions used during expert interviews

1. What types of goods do you carry?

2. What are your procedures for cargo acceptance, cargo shipment and storage?

3. What IT systems are there at your company. What business processes do they support? How many IT staff are there at your company?

4. What do you like most in your IT systems?

5. Are there any difficulties in using existing IT systems?

6. What is the error rate of existing IT systems operations?

7. Please tell us on situations where errors in IT system negatively affected your profits? If there were any cases.

8. Why don't you use latest IT systems available at the market?

9. Which ERP/WMS system do you use?

10. Please describe us situations where IT systems was accepted by your staff (dispatchers, warehouse workers, accountants) very well?.

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