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Mitigating data inaccuracy and supply chain challenges in Western Romania's automotive industry

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Abstract: The purpose of this paper was to emphasize the importance of data accuracy within internal logistics systems and their extended influence on supply chains in automotive industry through 6-month multiple case studies conducted on 3 first tier original equipment manufacturers (OEM) based in Western Romania. The study investigates the most common causes of data inaccuracies among automotive suppliers and their approaches to reduce consequential supply chain issues and be more agile. Data collection and analysis revealed that main issues arise due to ordering quantities mismatching actual customer demand, a wide range of order lot sizes, lead times and delivery reliability concerns and the reluctance to shift away from mainstream cost-effectiveness and towards strategic added value thinking. These issues sourced significant other related operational challenges such as excessive inventory, short-term stockouts and subsequent express shipping services or product-related inconveniences (quality and capacity levels, contracted volumes and dedicated lines). The paper sources different logistics and supply chain strategies used by the 3 OEMs, their features and operational performance, as well as their overall effectiveness, which can be applied by other automotive industry suppliers to improve own results. Introducing more reliable real-time data collection tools and performance metrics has started hauling more focus towards solving these prevalent issues with some ongoing improvement projects showing up to 25% better results. For one of the 3 OEMs introducing a new warehouse management system has already sourced an overall quality increase (5 percentage points) due to a 60% higher utilization of its production equipment.

1 Introduction

The automotive industry is one of the most important industries worldwide, driving investments, employment and innovations throughout its highly competitive supply chains, both vertically and horizontally. Battery-electric vehicles (BEV) are the new trend (14.6% market share and an impressive 37% increase in sales, 2023) as car sales in the EU reached 10.5 million units (13.9% year-on-year increase) based on The European Automobile Manufacturers Association (ACEA) 2023 report. According to ACEA at EU level only the automotive industry sources, directly and indirectly, 13.8 million jobs (11.5% of EU manufacturing jobs and 6.1% of overall EU employment) in its 322-vehicle assembly, engine and battery production plants and is the leading investor in R&D with almost 60 billion euros (31% of total spending, 2022). Dacia and Ford are the pillars in Romania (13% of GDP, 20% of the manufacturing industry and 30% of exports, 2023), enabling around 230,000 specialized jobs within more than 500 suppliers across the country. Last year Automobile Dacia produced 322,086 units (2.3% year-on-year increase) in Mioveni, while Ford Otosan's Craiova plant made 190,964 units (2.2% year-on-year decrease). Nevertheless, their combined output exceeded half a million units (513,050 cars made in Romania) for the second year in a row (0.7% year-on-year increase). The longest highway in Romania (A1) lacks a 140 km connection between Pitesti and Sibiu (called "the Dacia highway") along the Olt Valley single carriageway (DN7) and there is currently no highway connection (120 km on the DN65 single carriageway) between Craiova and Pitesti (called "the Ford highway"). Dacia is market leader in Romania (33% share with 46,124 units sold in 2023), but both carmakers sell less than 10% of their volumes on the local market as most of their production is shipped to export destinations in the EU. Dacia ships more than 8,000 assembled cars (by truck and/or train) every week to its distribution centre (DC) in Valenton (France) by rail, the Port of Constanta (for transit towards non-EU destinations by sea) or Germany (delivery lead-time is 2-4 days by road). A further 600 trucks leave the International Logistic Network (ILN) from Mioveni with containers of CKD and SKD kits (representing two-thirds of the Automobile Dacia plant production output) to be assembled elsewhere in Renault Group plants (Africa, South America or Asia). Ford also ships 90% of its production abroad, most of it by train (70%) to Neuss, Germany and the rest via road (25%) and sea (only 5% is shipped through the port of Constanta). Up to 600 cars (by rail) leave from Craiova every day towards Ford dealerships throughout Western Europe via the Railport Arad intermodal terminal in Curtici (Romania-Hungary border).

A major share of the automotive supplier network is concentrated in Western Romania, where important multinational brands have set up and extended capacity in recent years and experience business growth [1]. Reduced product life cycles, engine downsizing, increasing prevalence of head-up displays (HUD) and the shift towards electric vehicles (EVs) all mean that carmakers have to balance out integrating innovative technologies [2] fast whilst also being able to plan out an operational and competitive business unit [3,4]. A reliable and supporting supplier network is vital in such a challenging setting and its appropriate design (location, alternates and preferred selection) will determine the extent of a dependable and relevant data interchange system [5-8]. Adapted and appropriate logistic system choices (own/external warehouses, in-house logistics department/third-party logistics (3PL) externalizing and distribution centre (DC)/logistics service providers (LSP), etc.) will have a major effect on cost structures, delivery times and quality of data [9-13]. The overall performance of the company's internal organization, logistics (inbound, production scheduling, outbound) and supply chain management can be measured against its level of inventory [14,15]. This is because an actual JIT production strategy with properly balanced flows will not face inventory fluctuations that may cause excess amounts or, worse, stockouts and thus show the degree of its leanness [16,17].

The current study addresses the following research questions (RQ): what is the proper balance between process standardization and operational flexibility to achieve a competitive edge? (RQ1); what are the main contributing factors leading to data inaccuracies within a company's logistics department and its associated supply chain? (RQ2); what is the most efficient internal system for measuring and tracking real-time data and allowing for fast correction of errors within the production and logistics flows? (RQ3). This paper is the result of an ambitious research project carried out within the logistics departments of 3 multinational first-tier original equipment manufacturers (OEM) during a semester (total of 26 weeks) to assess the accuracy of specific data (inventory, forecasting and production) and quantify its influence on internal logistics KPIs and short loop supply chain (supplier-manufacturer-customer) performance.

2 Literature review

Data accuracy acts as a critical factor for significantly enhancing internal logistics performance and flow efficiency from inbound to outbound and within its corresponding supply chain. The dynamic of the automotive industry challenges OEMs and their supply chains to adapt and reconfigure processes to meet changing customer demands (downsizing, shift towards EVs, environmental policies) while in the meatime tackling supply chain disruptions, workforce shortages and integrated data management issues [18].

Agility is invaluable to maintain a competitive edge in a highly cost-effective oriented industry, especially since EVs have gained more and more market share on EU level in recent years [19]. Most automotive industry suppliers (OEMs, upper and lower tier suppliers) aspire to manage a reliable and accurate production system with room for innovation. However, finding the optimum balance between process standardization (to minimize in-house inaccuracies) and operational flexibility (to facilitate integrating new projects) is often daunting, especially in the short and medium term [20]. This is especially challenging since an EV's product life cycle (battery technology, charging infrastructure, government incentives) is still rather new in the automotive industry setting. In addition many OEMs still struggle with data silos (departments), outdated or rigid ERP systems and a lack of aggregate data integration on supply chain level hindering their ability to make inspired quality data-driven decisions. Employee induction, training and incentives are thus essential to promote responsible data handling practices and achieve higher data accuracy through gradual improvements based on experience.

Accuracy of data (relevant, real-time, synchronised and integrated) throughout internal logistics processes is critical for an effective operational performance in the long-term. The main contributing factors leading to data inaccuracies are the lack of standardization, human errors and scarce integration within the automotive supply chain [21]. On an individual level (automotive manufacturer or supplier), the most common sources of data discrepancies are manual entry errors, software inconsistencies and/or departmental silos which impact several internal decision-making processes (production planning, inventory levels, resource allocation). Focusing on relevant data, simplifying processes, understanding and explaining the role of data accuracy across departments will improve both production and logistics flows and improve inventory levels, resource allocation and operational performance [22].

Optimization is omnipresent in improvement projects concerning production and warehouse layout, logistic flows (inbound and outbound), inventory management and industry 4.0-specific tools implemented on the shop floor [23]. Well-designed intralogistics is not enough however. Automotive manufacturers also need a clear and reliable system for tracking data, allowing for the identification and correction of errors at their source (root cause). Data management structures, real-time relevant data sharing and ownership across departments can help improve data accuracy significantly. High-quality data is crucial for effective decision-making, allowing for a more targeted analysis and enables more relevant impact on overall productivity and operational performance [24].

3 Methodology

The methodology of the paper is based on a multiple case study conducted through 6-month research contracts (one was extended to a total duration of 11 months) within 3 first tier original equipment manufacturers (OEM) from Western Romania. Forecasting, planning & scheduling and performance management data from the last 5 years (2018-2022) was studied with relevant professionals of the 3 OEM's logistics departments. The final reports submitted upon completion of the carried out research are subject to non-disclosure agreements (NDA), as is most of the data collected within the 26 weeks of collaboration (2023).

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Each of the OEMs has consented some sets of data to be published but not to the same extent therefore some sets are incomplete or have been slightly modified to ensure upholding all NDAs properly. Subsequent conclusions (partially) might not seem entirely relevant and partial limitations for each set of data are to be expected.

Production planning is based on relevant data (historical, projected volumes and actual customer orders) in order to compile a more reliable forecast, each of the 3 OEM's having different techniques. Projected volumes are increasing on a year-to-year basis in all 3 cases (7-12% on average for OEM 1, 3-8% for OEM 2 and 2-6% for OEM 3) thus the Holt-Winters exponential smoothing method was the most appropriate choice to process forecasting data accuracy. Holt-Winters exponential smoothing (or triple exponential smoothing) uses a smoothing factor (α), trend (β) and seasonality (γ) coefficients to improve forecast accuracy. The multiplicative method is more suitable for the automotive industry and was thus used in computations by all 3 OEMs. This is because the automotive industry exhibits seasonal patterns (new product launches, market volatility, high and lower sales seasons, holidays) and non-linear trends that are handled better by the multiplicative method since the simulations are also done for at least 1 full business year (and not short-term forecasting). After simulating different scenarios for the entire year, results were refined for shorter timespans as well (semester, trimester) upon request. Forecasted levels for each of the 26 weeks were based on projected volumes and smoothed exponentially with trend and seasonality (α=0.2-0.3; β=0.25-0.35; γ=0.4-0.6) by each of the 3 OEM's production planners. The exact smoothing factor (α), trend (β) and seasonality (γ) coefficients used by the OEMs are subject to the agreed and signed NDAs. The mixed team was tasked to provide a range of applicable solutions and improvement proposals by the end of the research contract. Our proposed approach was to target a smoother average throughout a complete business cycle (52 weeks) while also using 3-6 months shorter cycles to dynamically adjust outputs and increase accuracy. A slight added weight (α) was given to more recent data, but longer-term trend (β) was preferred with only marginal adjusting for the seasonal smoothing coefficient (γ) being necessary.

Actual forecasting accuracy results presented within the research paper are very limited (due to heterogeneous NDA terms of the 3 OEMs regarding consented datasets). Therefore, quantitative and qualitative data is aggregated and averaged for a total of 6-11 months. The (partial and ongoing) results of our individually submitted proposals combine practical solutions from each OEM's logistics professionals and theoretical methods from academic literature to attain optimum outcomes.

4 Results

All 3 multinational automotive industry OEMs are located in the Western region of Romania and are tier 1 supplier for all customer brand and model ranges. Nevertheless, despite certain similarities that are characteristic to the industry (main characteristics), the OEMs also have some differentiating features highlighted in Table 1.

Table 1 Overview of each OEM's characteristics

features		OEM 1	OEM 2	OEM 3
Production	type	standard	standard	standard
	technology	superior	above average	average
	volume	very high	high	high
Warehouse	own	yes	yes	yes
	external	yes	DC	yes
	management	in-house	in-house	outsourced
Data	ERP	new	standard	standard*
	KPIs	real-time*	real-time	real-time
	employees	mix*	mix	mix

The features that are compared across the OEMs are production (type, technology, volume), warehouse (own, external, management) and data (ERP, KPI and employees). In terms of production, all manufacture standard products involving industry innovations, fitted on any car brand or model (across all major car companies), as outlined in Table 1. There are technology differences, with OEM 3 having rather average technology-encompassed products, while the others have above-average (OEM 2) and superior outputs (OEM 1). Volumes are high for 2 of the 3 OEMs, as they each supply important amounts for their customers, whereas OEM 1's volumes are very high due to a larger product range (brand and model-specific requirements) delivered. Raw materials and components, as well as finished goods, are stored in both own and external warehouses, only OEM 2 not having an own external facility and using a distribution centre (DC) instead. Warehouse management is done in-house (OEM 1 and OEM 2), except for OEM 3 who has outsourced this activity to a third-party logistics (3PL) service provider. Data management is rather different, as only OEM 2 uses an industry standard enterprise resource planning (ERP) software tool. OEM 3 has added significant extra features (specific input-output reports) to enhance its data analysis to its existing ERP, whilst OEM 1 is currently transitioning the switch to a new ERP system and thus replacing the one it has previously been using for over a decade. All OEMs use systems that collect, show and monitor real-time data, only OEM 1 still having some processes where some data, decisions and reports have to be approved manually before being subsequently computed. There is a good balance of young and experienced employees in all 3 OEMs', with OEM 1 having more novice employees that need to be inducted and properly trained after termination of their internships in order to start handling some of the company's projects. OEM 1 has the highest volumes (new projects and facility extension are currently under way) and is therefore more active in the hiring process than the other 2 analysed business units, where volumes are more stable.

Table 2 Overview of OEM 1's excess inventory per semester

Materials and components	Semester usage (units)	Monthly average (units)	Excess quantity (units)	Excess/semster usage (ratio)	Excess/monthly usage (ratio)
Supplier 1	151	25.16	518	3.43	20.58
Supplier 2	160	26.66	480	3.00	18.00
Supplier 3	191	31.83	512	2.68	16.08
Supplier 4	68	11.33	172	2.52	15.17
Supplier 5	150	25.00	300	2.00	12.00
Supplier 6	942	157.00	1404	1.49	8.94
Supplier 7	830	138.33	1109	1.33	8.01
Supplier 8	5320	886.66	6469	1.21	7.29
Supplier 9	640	106.66	765	1.19	7.17
Supplier 10	2190	365	-872	-0.39	-2.38
Overall average*	1762	293.66	4921	2.79	16.75

Table 2 outlines the forecasting, ordering and storage issues of OEM 1 in regard to some of its main raw materials and needed components for the manufacturing process. OEM 1's suppliers are mainly from Europe (Central and Eastern Europe) and Asia (East and Southeast Asia). The logistics department is based on a functional unit system where an employee fulfils a specialized role within small (3-5 members) or average teams (6-10 members) tasked with specific organizational functions. Each role has a high degree of autonomy, even interns or newly hired employees, and has at least one back up colleague who can temporarily stand in and take over corresponding tasks. Rising volumes (new projects, new products) increase the amount of orders each role has to process, regardless of the number of customers, product range, models and associated specific requirements, creating an unbalanced workload. The planning department has access to the company's forecast, but each planner (3 levels) decides what amount to actually order, being able to personally adjust the quantity ordered. More experienced planners will tend to add a small margin (up to 15%), whereas the younger and less experienced ones will tend to add up to 50% or even double the ordered amount in view of rising volumes, repetitive orders and long-terms contracted quantities. This choice will however increase the delivery lead time from the supplier and also bottleneck the warehouse, both own and external, its reception and storage capacity (recurring issue). Sometimes the ERP system shows a shortage of materials, but the truck is actually at the plant waiting to be unloaded (physically) with no available storage capacity within the own warehouse (waiting time: 4-8 hours), causing further delays in production. These issues can be found within the data shown in Table 2, as for the selection of 10 materials and components there is an average excess of inventory (2.79 semesters or 16.75 months) that would last for almost 3 semesters (18 months). The amount of inventory for some raw materials and components (suppliers 1-5) significantly exceeds monthly usage in production (12-20 months), congesting the warehouse, generating storage risks and causing imbalances. Materials from supplier 1 have an average monthly use of 25 units with inventory level being at 518 units (more than 20 times the required amount), whereas deliveries from supplier 10 are backlogged: 365 units/month (on average) are needed in production with a shortage level of 872 units (2.38 months), causing further scheduling delays. The other suppliers (6-9) have an inventory excess corresponding to 7-9 months, whilst other material surpluses, not shown in the table, range from 4-6 semesters using up unnecessary storage capacity, whilst others may be subject to further stockouts (e.g. supplier 10). These issues are then transferred to the shop floor, where it is very difficult to make up for the time lost with the reception, unloading and storage procedures and urgent and quick shipments are sometimes needed to compensate, as shown in Table 3. An online unloading schedule was introduced in 2023 for an improved planning of truck arrivals with dedicated time windows for each LSP with regular deliveries (and open slots for spot contractors), enabling better tracking of incoming materials (and confirmation of their reception) and after only 3 months using the system is mandatory for all LSPs arriving to unload at the warehouse gates.

Table 3 Overview of express shipment deliveries of OEM 1 towards main customers per semester

Express shipments	Deliveries (units)	Main reason	Price variation range (%)	Maximum amount (monetary units)	Total amount (monetary units)	Average price (monetary units)
Customer 1	17	constant	15-20%	23,806	106,346	6,255
Customer 2	6	spread	10-15%	11,200	59,727	9,954
Customer 3	14	peak	25-30%	11,200	38,346	2,739
Customer 4	6	spread	10-15%	2,570	12,032	2,005
Customer 5	11	shortage	25-40%	9,850	31,097	2,827
Overall average	10	constant	20-30%	11,761	49,509	2,475

Table 3 presents express shipments to some of OEM 1's customers within a semester (54 such deliveries in 6 months). While some of the urgent shipments are also due to external factors (peaks, shortages and unforeseen issues), most come about on a rather more regular basis due to similar reasons (customer 2 and 4) or are even constant occurrences (customer 1) tying up important amounts of working capital (almost 250,000 monetary units). Express deliveries for customer 4 have the lowest average prices (2,005 units) and lowest variation range (10-15%), the highest variation adding up to 28%. Customers 3 and 5 have similar average prices (2,739 and 2,827 units) and the highest average price variation ranges (up to 30-40%) with some shipments being rated 3-4 times higher than their average. Express deliveries to customer 2 are 4 times higher (9,954 units) than the overall average (2,475 units) and represent 24% of the total amount of shipments (247,548 units). With an average price of 6,255 units (2.5 times higher than the overall average), the 17 deliveries to customer 1 represent almost a third (31%) of all express shipments and almost half (43%) the total amount spent on the fastest form of dispatching.

This frequency of these quick shipments is also due to a range of new projects coming in and despite an extension of the manufacturing plant (new production area with a direct connection to the automated warehouse storage system) which is currently under way, it will not be completed until 2025, therefore production capacity is at full tilt, but also bottlenecked by unbalanced ordering levels. Overrating storage capacity (which has lost space due to shop floor being increased), also means backlogging production and not fully using manufacturing capabilities which in addition to the longer supplier lead times generate unproductive waiting times (longer production lead times, delayed loading of orders) and the risk of not delivering on time. Most customers are multinational carmakers located in Central Europe and have dedicated production lines (just in time (JIT) or just in sequence (JIS) type production systems), whereas the rest have their products manufactured in a flexible system (FMS), ranging from front-end to back-end processes. Regardless of brand and/or model range positioning, automotive manufacturing companies have high downtime costs, therefore idling or stopping production lines because of suppliers' delivery issues is not acceptable. Reliable suppliers with high service rates (orders delivered on time and in full, OTIF) are important all across the automotive supply chain, with special emphasis on higher tiers. OTIF puts pressure on all tiers and sometimes on-board couriers (OBC) are used to hand-carry certain components and parts in order to ensure on-time deliveries and avoid stopping a customer's production line.

Table 4 Overview of OEM 2's yearly production planning figures for a range of suppliers

Materials and components	Yearly usage (units)	Monthly average (units)	Minimum variation (%)	Maximum variation (%)	Average variation (%)
Supplier 1	2,000	166.66	10	70	29.17
Supplier 2	960	80	10	100	32.50
Supplier 3	522	43.50	17	100	27.59
Supplier 4	504	42	71	100	83.33
Supplier 5	336	28	14	100	47.62
Supplier 6	91	7.58	18	124	69.23
Supplier 7	1,000	83.33	20	100	63.33
Supplier 8	3,200	266.66	12	100	45.83
Supplier 9	432	36	0	150	58.33
Supplier 10	324	27	33	167	61.11
Overall average	936.9	78.07	21	111	51.80

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Table 4 highlights OEM 2's production variation for a range of materials and components. Despite the OEM's high volumes, the average yearly variation was just above 50% for all material and component orders passed to the selected suppliers. Orders to suppliers 1-3 even had an average variation of around 30% throughout the year, a very decent accuracy level given the recent global supply chain challenges (Covid-19 pandemic, chip shortage, increased costs and price volatility). With 2 exceptions (suppliers 4 and 10) minimum variation is under 20%, whereas except the cases where no orders are placed (100% variation), maximum variations range between 60-90%, most cases however usually average between 30-50%. Two thirds of supplier orders match a batch-size ordering pattern, therefore our aggregated variation calculations show higher fluctuations and unpredictability than is actually the case in practice. Supplier 3 has the best forecasting, as their actual order variations only range between 17-24% throughout the entire year (increased predictability), whilst supplier 9 has 2 months with a perfect match between its forecasted orders and its actual passed order levels. Having a rather stable ordering pattern in the short loop supply chain (supplier-manufacturer-customer) with smaller fluctuations will improve the flow of goods and delivery reliability as well as reduce the risk of generating an upstream bullwhip effect (BE). Suppliers 9 and 10 also experience both a zero order situation, as well as a doubling of the order level throughout the year, thus yielding higher than average maximum variations (150% and 167%). To accommodate rising volumes OEM 2 decided to increase shop floor space on its premises instead of contracting an external warehouse and use a distribution centre (DC) closer to its customer locations. With no external warehouse to rely on in case of excess storage needs, OEM 2 relies on its forecasting and production planning to be accurate in order to deliver finished goods to its customers. The logistics department is divided into teams and each team focuses on specific customers and product ranges, as their orders will be divided among members based on the characteristics and complexity of the entire process (supplier orders, production lead times and delivery requirements). All in all, OEM 2's forecasting and planning in fairly reliable (forecasting accuracy has increased by 22% on a year-to-year basis, while production planning sourced a 17% improvement) with peaks and troughs being properly handled due to standard production levelling techniques. In addition, within the analysed business year (2022), only 3 express shipments were required due to a more balanced ordering-manufacturing cycle. The business unit's excellent logistics performance has been noticed by upper management and the facility will start managing the same range of services for one of the group's additional manufacturing plants starting 2024.

Table 5 Overview of OEM 2's delivery characteristics from the distribution centre towards end customers

Distribution center	Driving time (hours)	Pick-up day	Outsourced to	Expected service level (%)	Delivery type
Customer 1	58 min 1h10min 3h28min	Thursday	LSP1	95	JIT
Customer 2	3h46min	Wednesday	LSP2	85	JIT
Customer 3	4h03min	Friday	LSP3	98	JIS
Customer 4	7h40min	Wednesday and Friday	LSP1	95	JIT
Customer 5	21h19min	Monday	LSP 3 or LSP4	85	JIT
Overall average	7h44min	N/A	N/A	91.6	JIT

Table 5 presents the delivery characteristics for some of OEM 2's most important customers. OEM 2's DC is located at 15h52min driving time from Western Romania (border crossing times are not included). Border crossing (Romania-Hungary) for trucks includes waiting and document processing times at one of the 5 borders. Nadlac II is the most congested because it is the gateway to the A1 highway, where waiting times are 8-24 hours and can even sometime reach 48 hours. Bors II is an alternative, but also implies a 2 hour detour (A3 highway). Customer 1 has 3 possible locations for delivery from the distribution centre: delivery location 1 (DL1) has a 58 minute driving time, similar to DL2 (1h10min driving time), whereas DL3 is reached within 3h28min driving time. An average of 1h52min is thus needed with all 3 DLs expecting just in time delivery and a 95% service rate from LSP1 (the same LSP for all 3 DLs). Customer 4 and customer 1's 3 delivery locations are managed by the same logistic service provider (LSP1), only one other LSP (LSP3) having more than 1 customer to manage (customers 3 and 5). Customer 4 also has the second highest delivery lead time (7h40min) and has two alternative days (Wednesday and Friday) available for pick-up. Customers 2 and 5 have the lowest expected service level (85%) with customer 5 having two alternative LSPs due to its highest delivery lead time (21h19min). Customer 3 has the highest required service level (98%)

and is the only one to expect a Just-in-Sequence (JIS) delivery, all others using the typical automotive industry standard, the Just-in-Time (JIT) delivery.

Table 6 Overview of OEM 3' manufacturing process KPIs

Production data	Availability increase (%)	Performance target (%)	Performance level (%)	Quality level (%)	OEE (%)
Process 1	62	95	96	NDA	NDA
Process 2	66	95	94	NDA	NDA
Process 3	71	95	97	NDA	NDA
Process 4	46	95	87	NDA	NDA
Overall average	61.2	95	93.5	NDA	NDA

Table 6 presents the OEM 3's most important manufacturing processes and their overall performance after implementing an extended warehouse management (EWM) system within the first semester of 2023, as an extra add-on to its current ERP system. Actual quality levels and overall equipment effectiveness (OEE) measured values were subject to agreed NDA terms, only broad comments being consented for paper publishing. Despite an investment required to attach the EWM to the company's current ERP system, the return on investment (ROI) was attained sooner than expected. OEM 3 has both an own and external warehouse, but decided to focus on its core competence (manufacturing) and contract an LSP for part of its supporting logistics processes (warehouse and distribution management). Only the company's outbound logistics is outsourced (3PL), therefore an internal logistics department is required to support the production process (including planning, scheduling and levelling). Implementing the EWM has enabled better inventory accuracy, improved real-time process flow tracking and automatically-triggered replenishment (e-Kanban system). The increase in time availability (by an average of 61.2%) has also triggered a performance level increase of around 10% for all processes, most notably for Process 1 (96%) and Process 3 (97%), both above the set target, whereas Process 2 was just 1 percentage point below (94%). Process 4 experienced some unexpected technical issues and a temporary minor backlog which affected its rating (87%) within the current analysis. Nevertheless, after the issue was solved, the process had a similar output, matching the other processes' performance (within the same monitored timespan) therefore results should be more balanced towards the end of the business year (2023). The performance of each process is the average of the performance of the 3 shifts in the company per process, the morning and day shifts having slightly higher productivity figures (up to 3 percentage points higher) than the night shift (around 5 percentage points lower than the average of the first 2 shifts). Moreover a 5 percentage point quality level increase has been observed, as well as an OEE increase of 12 percentage points, key takeaways after only 6 months of implementation.

Table 7 Overview of OEM 3' warehousing performance KPIs

Warehousing data	Initial performance level (%)	Current Performance level (%)	Performance dynamic (%)	Performance target (%)	Measured vs. target performance level (%)
Process 1	NDA	NDA	+20	NDA	+4
Process 2	NDA	NDA	+16	NDA	+3
Process 3	NDA	NDA	+13	NDA	+2
Process 4	NDA	NDA	+10	NDA	0
Overall average	NDA	NDA	+14.75	NDA	+2.25

Table 7 outlines OEM 3's warehousing performance KPIs in terms of overall inventory accuracy for all inbound individual references and their main categories (raw materials, components, subassemblies, MRO) after implementing and connecting the extended warehouse management (EWM) system to the company's tracked KPIs. Integrated within the company's ERP system since early 2023, the system has improved overall reference accuracy for each of the 4 main processes (data is aggregated and averaged for a total of 11 months). Initial and current performance levels, as well as the set performance target values were subject to agreed NDA terms, only the resulting dynamic, variation and achieved result (measured vs. target performance level) were consented for paper publication. Process 1's overall inventory accuracy shows an increase of 20 percentage points (an increase of 26% when comparing current to initial performance) thus exceeding the target performance level by 4 percentage points. Data for Process 2 indicates similar results with an increase of 16 percentage points for its current performance level (an increase of 19% from initial performance). Process 3 has the highest availability increase (see Table 6) which is also supported by its improved reference accuracy (13 percentage points increase of its performance level, 2 percentage points above target levels), an overall improvement of 16% in the last 11 months. Despite performing below average compared to the other processes in terms of availability (see Table 6), Process 4's warehousing results still met the target performance level. Data accuracy increased by 10 percentage points and showed an aggregated 12% increase in terms of a direct current to initial performance comparison. On an aggregate level, for all 4 processes, warehousing data shows an increase in current accuracy for all references of 14.75 percentage points (an increase of 18% when compared to initial performance) and an exceeded target performance level (2.25 percentage points on average and a 3% increase in relative figures). Actual results for the last month are not available (research contract ended), but they should fall within the same data range and confirm the aforementioned analysis. This was later confirmed by the OEM 3's logistics professionals who commented that "Results were as expected", validating the previous assumption (for business year 2023). High inventory accuracy (EWM), automatically-triggered replenishment (e-Kanban) and tracking operational performance and productivity in real-time (OEE) for OEM 3 meant an increase of the proportion of value added time (in total time), production efficiency and enabled a seamless flow of operations.

5 Discussion

The main objective of this research paper was to underline the relevance of data accuracy among tier suppliers from the automotive industry. Multiple-layered planning departments with unbalanced extra safety margins added up reduce the actual forecast accuracy and lead to excess inventory (up to 18 months) or stockouts (mismatched data in the system). Increased order quantities increase order lead times, impacting smooth operations flow (supplier delays, urgent order change regular scheduling, express shipments) and overall JIT production system. Express shipments are costly, but the cost of customer penalties for stopping their production line would significantly exceed the higher shipping rates. OEM 1 has good operational flexibility [25], but needs to enhance process standardization to improve cost-effectiveness, confirming that proper balance between the two is difficult to achieve in practice (RQ1). Nevertheless, the OEM 1's proven ability to integrate several new and challenging projects in the last 10 years have sourced multiple factory extensions in order to accommodate constantly growing volumes.

Customer-dedicated functional teams (within the logistics department) with complementary skills, collaborative spirit and shared accountability (both individual and team-based) are more adapted to specific project details and are more productive in problem-solving. Sharing information also leads to a better forecasting accuracy (lower overall variation compared to actual orders) and better overall production planning and scheduling (rare cases of express shipments, only 3 in the previous business year) with a reliable logistic system within the supply chain (DCs, LSPs and DLs delivering both JIT and JIS to automotive customers). OEM 2 has invested in training its employees to problem-solve and to then standardize knowledge within their groups and teams (RQ2). Understanding relevant data, simplifying processes and trusting each team member's role have significantly improved data accuracy across departments (both quantitative and qualitative), enabling smoother production and logistics flows and reduced inventory levels, boosting operational performance [26]. Stabilizing internal processes and procedures can also be a preventive response to an anticipated decline in business volumes on short or medium term, as suppliers tend to have primary data and first-hand evidence from the automotive sector.

Managing high volumes for automotive products with longer than average life cycles increases the importance of an efficient internal production process (proportion of added value) and seamless shop floor workflow. Shifting focus on core competence (manufacturing) means more resources are allocated to supporting activities of the production process (planning, operations, quality and continuous improvement) to increase productivity. Recognizing its strengths in manufacturing, OEM 3 strategically leveraged an external logistics provider (LSP) to manage a portion of its non-core outbound logistics processes (warehousing and distribution). This focus on core competencies streamlined internal operations (increase of time availability, performance levels and OEE) in support of the manufacturing process [27]. Implementing automated data tracking tools (EWM) also helps increase data reliability, inventory accuracy and the leanness of the overall production system. OEM 3 focused on improved operational performance (OEE) to maximize shop floor output [28] by improving data accuracy for inbound logistics (EWM) and outsourcing outbound logistics (distribution), indicating the value of process ownership (BPM) for automotive suppliers in order to source an approach that is most adapted to their specifics (RQ3). While improving operational performance might be a sign that OEM 3 is preparing to adapt to the anticipated automotive industry disruptions [29], it could also mean preparing for future growth on a more stable basis since its products have high aftermarket volumes as well (higher than OEM 1 and OEM 2).

This research delves deeper into the implications of data accuracy within an automotive manufacturer's internal logistics systems (forecasting, planning, and process management). Findings are representative, as existing research outlines the ripple effects of precise data [30, 31] within the supply chain, partially confirmed within this paper's results (efficiency and resilience), with additional insights into a future automotive industry supply chain where agility and responsiveness will become equally important. The limitations of the paper come from the NDAs, limiting the presentation of actual results obtained (analytical completeness), affecting reproducibility and validity of presented findings. In addition, the case studies have a strong empirical component (very specific internal and external challenges), affecting replicability of data and results which are acknowledged.

6 Conclusions

The overall results confirm the existence of internal logistics performance issues within the 3 first tier OEMs from Western Romania. OEM 1's main logistics issues are inventory-related, as overestimating actual demand creates excessive inventory (up to 18 months for the analysed raw materials, components and parts), as well as increased supplier lead times and insufficient storage capacity, causing production delays. Subsequently adding arbitrary margins to forecasted levels of activity affect the reliability of the production scheduling and burdens storage capacity. Needing to manually approve certain data modifications within the company's ERP system (automatic option is available) yields unproductive waiting times and other interconnected teams or departments to use data that has not always been updated (ERP system showing a lack of material, but trucks waiting for hours to be unloaded in front of the warehouse, outlining the value of real time data. Furthermore, in addition to excess inventory (tied up working capital), several express shipments (worth almost 250,000 units) had to be contracted to prevent stopping customer production lines (carmakers) and bear huge penalties. Being agile and finding the right balance between process standardization (cost-efficiency) and integrating new projects (business opportunity) with current operations already running close to full capacity makes achieving overall competitiveness challenging (short and medium term). On the other hand investigating the possible outcomes of integrating advanced machine learning algorithms could be an insightful future research topic. Machine learning algorithms incorporate and handle real-time complex datasets (while also automating the process) and could source superior demand forecasting accuracy. Dynamic inventory optimization based on lead times could prove to be relevant, as adjusting inventory levels based on real-time lead time data and supplier performance fluctuations would also explore the feasibility of collaborative forecasting with the OEM's key suppliers. In terms of capacity management multi-tier storage options such as automated storage and retrieval systems (AS/RS) could significantly improve warehousing space utilization and should be a reliable option for dynamic capacity allocation based on product characteristics and demand patterns.

OEM 2's main challenge lies within accurate forecasting and balanced production planning schedule. With no external warehouse and a distribution centre almost 16 hours away from the plant (in addition to border Hungarian border crossing procedures), on time deliveries (OTIF) are mandatory to uphold car manufacturer service levels (JIT and JIS). Forecasting accuracy has improved by 22%, also enabling a more balanced production planning schedule for the second semester of 2023. Only 1 carmaker requires a 98% service level rate and JIS delivery, whilst the others mainly expect a 95% level and JIT delivery, the furthest away customer (22 hours from the DC) only imposing 85% rate on the service level. Future research topics could delve into inventory optimization methods that integrate lead times, transportation times and varying service level requirements (SLAs) of geographically dispersed customers. Multi-echelon inventory models with strategically placed buffer stocks closer to distant customers or vendor-managed inventory (VMI) programs with key suppliers could further increase OEM 2'delivery reliability. Dynamic production scheduling simulations could also explore and test the effectiveness of different scheduling strategies on on-time in-full (OTIF) performance (85% vs. 98%) for JIT/JIS deliveries and provide valuable insights.

OEM 3's outsources its outbound logistics therefore proper inbound logistics and production performance are needed to avoid shipping delays to its 3PL and end customers. The e-Kanban (integrated in the EWM) automatically reorders raw materials, components, subassemblies and MRO, thus supplying the production process in an appropriate pace and contributing to a seamless production flow. Overall inventory accuracy for inbound logistics (warehouse) has improved by more than 14 percentage points (more than 18% in relative terms) in only 11 months with 3 of the 4 process-related materials exceeding their target performance levels (by 2-4 percentage points). Implementation of the EWM has boosted the company's performance on all levels, as availability has increased by more than 60%, performance by around 10% (actual levels are within the set targets) and quality has risen by 5 percentage points. The OEE rating is thus 12 percentage points higher after implementing the new additional data management system, validating the relevance of an improved process flow performance monitoring system with real-time, reliable and accurate data integrated within a customized ERP system. Based on these results some possible further research areas could study advanced predictive analytics within the EWM's automatic replenishment module such as material criticality, lead time variability, potential cost implications of stockouts or excess inventory and suggest dynamic reorder points for critical materials (optimizing reorder points for e-Kanban). Furthermore, to strengthen process reliability and a seamless flow of goods (inbound and within the factory) real-time data analysis could be integrated within the current EWM. Analysing sensor data to predict equipment failures and scheduling preventive maintenance can be leveraged to minimize downtime and disruptions in the production flow would increase availability to some extent. Increased machine availability would also enable real-time data to shift job priorities and optimize production sequencing, increase throughput of potential bottlenecks and resource allocation, ultimately maximizing Overall Equipment Effectiveness (OEE).

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