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Milan Đorđević
Sonja Kostić
Hrvoje Puškarić
Rodoljub Vujanac[1]
Srđan Atanasijević
Maja Đorđević

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DEFINING MATERIAL FLOW DEPENDING ON MATERIAL CHARACTERISTICS

Abstract: *To apply the principles of Logistics and achieve the objectives of customer satisfaction and cost reduction, the key point is to use the most suitable handling flow according to the type of material, i.e. its intrinsic, dimensional, economic and physical characteristics. For this purpose, standard guidelines have been developed to guide the choice of the most suitable type of flow according to the type of material.*

Establishing an optimal material flow within industrial settings, particularly those dealing with complex final products consisting of numerous components, poses a significant challenge. The effectiveness of such a flow hinges on various factors, notably the dimensions, cost, and quantity of parts within a logistic family. Thus, the classification of materials necessitates the development of a systematic methodology along with clearly defined limits. By selecting the recommended material flow strategy, organizations can realize substantial benefits, including notable reductions in inventory levels and logistics costs. This underscores the critical importance of establishing a robust system to manage material flow efficiently within industrial operations.

Keywords: *material flow, material classification, stock reduction, waste elimination, logistics*

1. Introduction

In the pursuit of operational excellence and competitiveness, businesses across industries continually seek to optimize their logistics processes (Narciso et al., 2010; Bartolacci et al., 2012; Rahimi et al., 2020). Essential to this is the strategic management of material flow, which plays a pivotal role in achieving objectives such as customer satisfaction and cost reduction. To effectively navigate the complexities of material flow, it is imperative to tailor handling strategies to the unique characteristics of the materials involved—be it their intrinsic properties, dimensions, economic considerations, or physical attributes. Standardized guidelines have been developed to aid in this endeavor, offering a framework for selecting the most appropriate flow type based on material type. However, within industrial environments, particularly those involved in the production of intricate final products comprising numerous components, the task of establishing an optimal material flow presents formidable challenges (Sendra et al., 2007; Doerr et al., 1996). The key to pulling this off lies in a deep understanding of things like dimensions, costs, and part quantities within logistic families. To get there, we'll need to develop systematic methods and clear classification criteria. This paper explores how crucial it is to create efficient material flow systems in industrial settings. It emphasizes the real-world advantages, like cutting down on

[1] Corresponding author: Rodoljub Vujanac
Email: vujanac@kg.ac.rs

excess inventory and saving money on logistics, that come from adopting the suggested flow strategies. Many autors in literature went through a comprehensive examination of these principles, organizations can effectively streamline their logistics operations and enhance overall operational efficiency (Wong et al., 2015; Kovács, 2018; Ha et al., 2011; Han et al., 2023; Brdulak & Zakrzewski, 2013).

To reduce the supply time and thus the costs, as well as to improve the quality of materials (elimination of scrap), it is necessary to define the most appropriate flow of materials (Davidovic, 2012) and (Bulatovic, 2013), or the strategy of supplying the production line with parts.

Main objective of material classification is to give the correct guidelines from time, cost and quality point of view, for each different type of material, according to the logistics rules, meeting the expectations of productivity (Regodic, 2014).

Within this objective, material classification allows to:

- build priority of action and the necessary level of attention to adopt in order to implement the logistic flow improvement, according to the material value;
- give indication of the most suitable logistic flow, according to ideal standard, starting from the production line requirements;
- suggest the stock level to be programmed at the Point of Use;
- give indication about the most suitable material call off system to support the recommended flow.

Starting from the material classification it is possible to make the "gap analysis" to prepare the plan for every part or for every logistic family, supported by benefit/cost analysis to be progressively implemented.

2. Material Classification

Material classification purpose is to establish a common methodology to classify parts thereby facilitating to identify the priority of action in planning logistic processes within the supply chain according to material characteristics (Goldsby & Martichenko, 2005), but also, to assess new programs logistic process or to evaluate existing process to plan improvements actions.

Production process constraints in automotive industry should also be considered:

- multi-vehicle/model assembly line loading could influence the increase of variation;
- the different process scroll could influence the reduction of variation.

Same components on different vehicle (models) could in fact fall into different "Logistic Family" (Logistic Family is group of parts with the same logistic flow from supplier up to Point of Use) even if these are part of the same commodity according to the product bill of material (e.g. in case of two models on two different lines, door handles are part of the same commodity but they could have different logistics flows depending on the complexity in each model).

The scope of material classification should only include those parts received at the production facility. Those parts which are integrated into a module should not be part of the material classification (i.e. Consigned parts, non consigned parts and directed parts included in modules).

Supplied modules should be treated by the customer (production facilities) as a single logistic family. The material classification of the modules components is in the Supplier scope.

The key characteristics of part for the material classification are cost, physical characteristics, and number of variations. The material flow will be more complex for expensive, bulky and parts with more variations (Vujanac et al., 2015). More vriations means taht one logistics family has

more then three diferent parts (family of seats can include more then hundred diferent disignes of seats).

2.1. Methodology of material classification

Material classification has to be done through several activities:

1) Collect data about parts used in the same production line (modal/tracked vehicle) and fill in the appropriate section of the "Material Classification Form" in figure 1.
2) Identify "Expensive" parts (Rule 1), "Bulky" (Rule 2) and "Many Variation" (Rule 3) see Table 1. Within A part apply Rule 1, 2 and 3 to identify AA1, AA2, AA3 class parts
3) For all AA Class items check if it is Bulky (Rule 2) or Many Variation (Rule3). If it is both Bulky and Many variations assign AA1 sub-class, if Bulky only assign AA2 sub-class, if it is Many Variations only assign AA3 sub-class. For all the other AA parts which are not Bulky or aren't Many Variations, classify them as AA4 parts.
4) Consider all the other A Class parts, identify items in AB Class (and split them into AB.1 and AB.2 sub-class according Rule 2 and 3, see next slide) and then to AC Class.
5) Identify items belonging to C Class (Rule)
6) All the other items are in B Class
7) Calculate for each item stock turnover ratio, to identify High, Medium and Low runners' items.

Table 1. Standard Material Classification and Rules

Class		Description	Subclass	Subclass Description		Recommended Rules
A	A	Expensive	AA1	many variation and bulky	include all expensive parts both bulky and with many variation	Rule 1
			AA2	bulky	include all expensive parts that are bulky too, but without many variation	
			AA3	many variation	include all expensive parts with many variation but not bulky	
			AA4	other expensive	include all the other expensive part not assigned to one of the previous sub-group	
	B	Bulky	AB1	many variation	include all bulky parts with many variation	Rule 2
			AB2	other bulky	include all the other bulky part not assigned to one of the previous sub-group	
	C	Many Variation	AC			Rule 3
B		Normal	B			Rule 4
C		Fasteners	C			Rule 5

Rule 1 (part is expensive)

The total value of the „Model Vehicle"/ „Tracked Vehicle" should be considered starting from the evaluated B.O.M. (bill of material) including the cost of all the components (from A to Z 100% of the components). Model/Tracked components must be sorted by decreasing value. Then identify the threshold. It is the value of the component above which the cumulative

value in about 50% of the whole „Model Vehicle“/ „Tracked Vehicle“. The threshold value should be used for the entire parts list (in case of multi-model production line, the threshold will be the minimum threshold among the different models). The „Expensive“ class should include the „High Theft“ items because of the value that they would have on external market, no matter if the purchase cost for the Company is lower than the threshold.

Rule 2 (part is bulky)
For standard container limit value for bulky parts is volume > 60 liters (references 1200mm x 1000mm x 50mm). Calculate parts volume starting from container volume and dividing for container density is allowed only in the early step of Material classification.

Rule 3 (logistcs family has more then three parts)
If single part is installed on the vehicle: a logistic family is complex if the part numbers of the family >=3. Three is a standard reference quantity. If any space issue/constraints would occur, use a lower quantity is admitted. A standard higher than 3 could be established for those parts with a high possibility of mistake during picking operation.
If parts are instaled on right and left on vehicle: a logistic family is complex if the part numbers of the family >=6.

Rule 4
Parts not assigned to Class A or Class C.

Rule 5
Fasteners (nuts, screw, bolts, springs, etc) and all parts with volume < 0,015 liters (references 25mm x 25mm x 25mm).

2.2. Material classification template (excel application)

Main objectives of Material classification template are:

- Help the user to complete a Material Classification, ensuring common inputs/outputs are followed, no matter which plant is using the tool.
- Provide users with a more efficient way to determine material classification for parts in current production and in planning new programs.
- Provide users with recommended flow types and line side stock quantity for all parts based on material classification.
- Perform analysis to determine gaps in the flow types and plan improvement action and projects.

Material classification template has to be done by line (mono or multi vehicle). Cells (excel) with formulas are write protected. In all worksheets, the user is only able to update fields that are not shaded (grey cells). All shaded fields are locked. Standard template has four worksheets. First three for input data: 1) “MaterialClassification” – main worksheet to input parts data; 2) “ContainerData”: – database with container dimensions and volumes; 3) “Reference Tables” – database with values used in the formulas of other worksheets.

Last one worksheet for summary of data “SummaryChartTables” – graphs and table to resume Classification results.

2.3. Eight steps of material classification

Implementation of material classification template is presented trough 8 steps.

Step 1
Fill in the “ReferenceTable” worksheet using the two tables below (figure 1). All the others must not be modified.

Step 2
Fill in the “ContainerData” worksheet (only the white fields table 2). Metric or English measurements unit should be used according

to region. Filling in both metric and English dimensions will allow the container code to be used in all studies. Metric based studies will refer to the metric data; English based studies will refer to English data. Once a container is added, its volume will be calculated automatically once the length, width and height are input.

Step 3

Fill in the "MaterialClassification" worksheet – General Information.

The first set of data to be input to the Material Classification worksheet references the plant, line, etc. where the study is being performed (figure 2).

The threshold value for expensive parts is automatically calculated based on Tracked Model/Modal Vehicle (mark (1) on figure 2). Measurement unit is either "English" or "Metric". All calculations performed will be calculated based on this selection (mark (2) on figure 2).

Step 4

In step 4 all part numbers have to be filled in the table „Material Data" (Part Number, Description, Logistics Family, Coefficient of use, Part Weight etc.) as in figure 3. All parts in a logistics family need to be listed, but only part used on Tracked Model will be used for calculation. Non tracked parts must be referenced to the tracked part.

Step 5

Fill in Cost and Containing Unit data (container code and container density). Cost per vehicle, container volume and part volume will be automatically calculated (figure 4).

Step 6

Expensive, Bulky and Many Variation will be automatically calculated according to data filled in the previous columns as in figure 5. Each value can be manually overridden to consider special requirements (e.g. High theft parts may fall below the expensive threshold, but they must be treated like expensive parts).

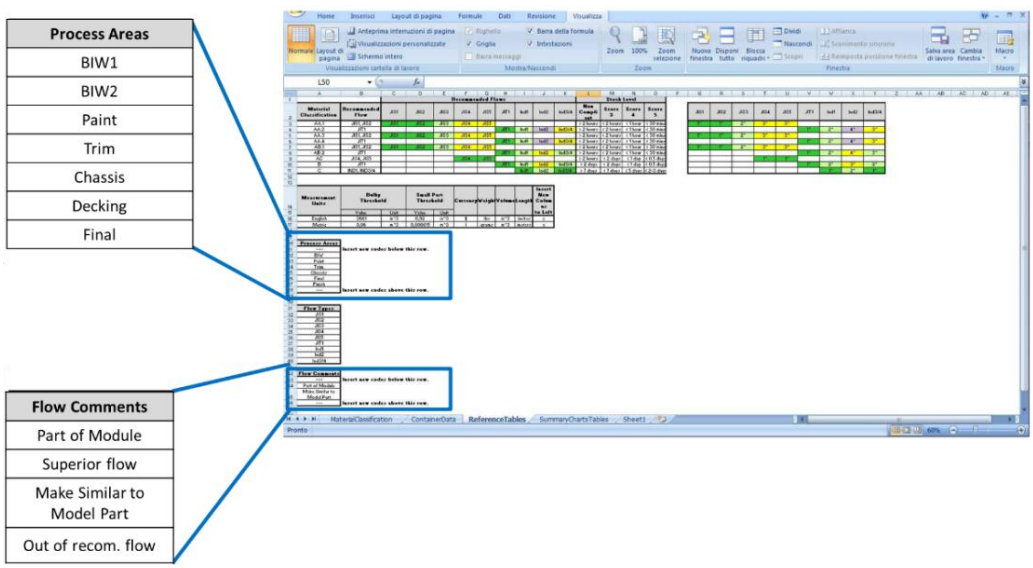


Figure 1. Material classification template

Table 2. Container Data

	Internal Dimensions			
Container Code	L [mm]	W [mm]	H [mm]	Volume [m^3]
4147	400	300	147	0,018
4201	1200	1000	975	1,170
4202	1200	1000	990	1,188
4203	1000	800	750	0,600
4204	1600	1200	750	1,440

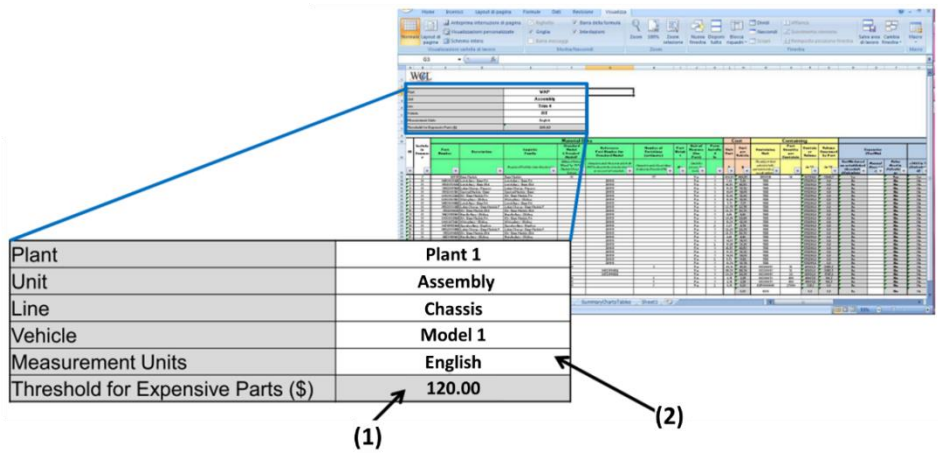


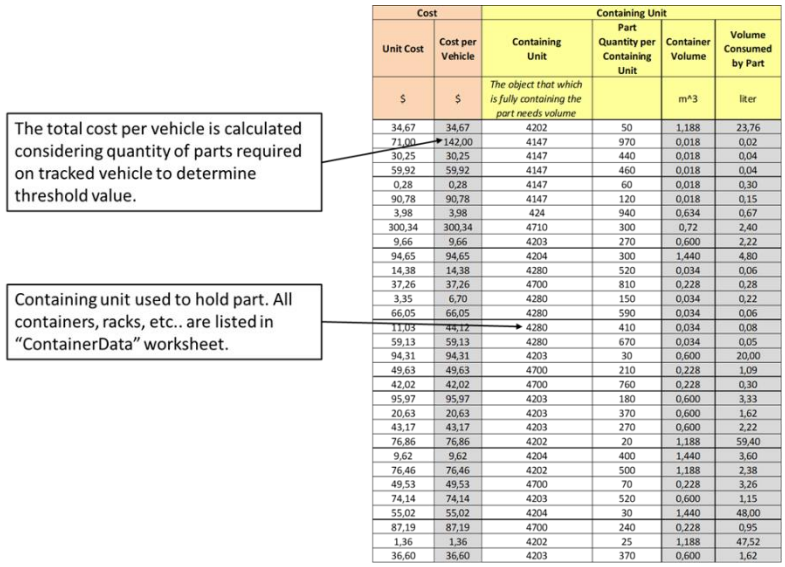
Figure 2. General information

ID	Include in Summary Data	Material Data							
		Part Number	Description	Logistic Family	Standard Model (Tracked Model/ Vettura Modale) or Option	Reference Part Number for Standard Model	Number of Variations (estimate)	Part Weight	Unit of Measure (for Part)
					Allowed Values: "Blank" or "M" for Modale/Tracked Vehicle	*Complete only for parts which do NOT belong to the standard model or are part of a module.*	*Complete only if part does belong to Standard Model*	*kg*	*Could be pieces, kg, mm*
1	Y	PM222	Door Module	Door Module	M		55		Pcs
2	N	243808372	Door part 1	Door part 1		PM222			Pcs
3	N	909760815	Door part 2	Door part 2		PM222			
4	N	917330909	Door part 3	Door part 3		PM222			
5	N	403204923	Door part 4	Door part 4		PM222			
6	N	265975363	Door part 5	Door part 5		PM222			
7	N	566859210	Door part 6	Door part 6		PM222			
8	N	684164772	Door part 7	Door part 7		PM222			
9	N	563211020	Door part 8	Door part 8		PM222			Pcs
10	N	659970812	Door part 9	Door part 9					Pcs
11	N	810468255	Door part 10	Door part 10					Pcs
12	N	234304596	Door part 11	Door part 11					Pcs
13	N	125816663	Door part 12	Door part 12					Pcs
14	N	202545485	Door part 13	Door part 13					Pcs
15	N	163525055	Door part 14	Door part 14					Pcs
16	N	521319925	Door part 15	Door part 15					Pcs
17	N	891768142	Door part 16	Door part 16		PM222			Pcs
18	N	647336688	Door part 17	Door part 17		PM222			Pcs
19	N	495515544	Door part 18	Door part 18		PM222			Pcs
20	N	999065069	Door part 19	Door part 19		PM222			Pcs
21	N	943524666	Door part 20	Door part 20		PM222			Pcs
22	N	870851007	Door part 21	Door part 21		PM222			Pcs
23	N	480162655	Door part 22	Door part 22		PM222			Pcs
24	N	632193049	Door part 23	Door part 23		PM222			Pcs
25	Y	272965536	Pedal Assy - Accelerator	Pedal Assy	M		3		Pcs
26	Y	427297966	Pedal Assy - Accelerator	Pedal Assy		272965536			Pcs
27	Y	482387013	Pedal Assy - Accelerator	Pedal Assy		272965536			Pcs
28	Y	827204225	Inner pipe 1	Inner pipe	M		2		Pcs
29	Y	754646215	Inner pipe 2	Inner pipe		827204225			Pcs
30	Y	966106368	GPS unit	GPS unit					Pcs

Fill in this field , only module will be tracked. Ensure to include in summary data.

Designate part to module if applicable. All parts in modules must be added to worksheet (in the sheet e.g. PM222) but should not be included in the data summary.

Figure 3. Material Data from PFEP (plan for every part)



The total cost per vehicle is calculated considering quantity of parts required on tracked vehicle to determine threshold value.

Containing unit used to hold part. All containers, racks, etc.. are listed in "ContainerData" worksheet.

Cost		Containing Unit			
Unit Cost	Cost per Vehicle	Containing Unit	Part Quantity per Containing Unit	Container Volume	Volume Consumed by Part
$	$	*The object that which is fully containing the part needs volume*		m^3	liter
34,67	34,67	4202	50	1,188	23,76
71,00	142,00	4147	970	0,018	0,02
30,25	30,25	4147	440	0,018	0,04
59,92	59,92	4147	460	0,018	0,04
0,28	0,28	4147	60	0,018	0,30
90,78	90,78	4147	120	0,018	0,15
3,98	3,98	424	940	0,634	0,67
300,34	300,34	4710	300	0,72	2,40
9,66	9,66	4203	270	0,600	2,22
94,65	94,65	4204	300	1,440	4,80
14,38	14,38	4280	520	0,034	0,06
37,26	37,26	4700	810	0,228	0,28
3,35	6,70	4280	150	0,034	0,22
66,05	66,05	4280	590	0,034	0,06
11,03	44,12	4280	410	0,034	0,08
59,13	59,13	4280	670	0,034	0,05
94,31	94,31	4203	30	0,600	20,00
49,63	49,63	4700	210	0,228	1,09
42,02	42,02	4700	760	0,228	0,30
95,97	95,97	4203	180	0,600	3,33
20,63	20,63	4203	370	0,600	1,62
43,17	43,17	4203	270	0,600	2,22
76,86	76,86	4202	20	1,188	59,40
9,62	9,62	4204	400	1,440	3,60
76,46	76,46	4202	500	1,188	2,38
49,53	49,53	4700	70	0,228	3,26
74,14	74,14	4203	520	0,600	1,15
55,02	55,02	4204	30	1,440	48,00
87,19	87,19	4700	240	0,228	0,95
1,36	1,36	4202	25	1,188	47,52
36,60	36,60	4203	370	0,600	1,62

Figure 4. Parts Cost per Vehicle and Parts Volume

Step 7

Based on Expensive, Bulky and Many Variation values, material classification is determined automatically (figure 6). There is an option for a manual override e.g. when there are multiple parts in a logistics family non tracked parts must be given the same classification as the tracked part.

Expensive (Yes/No)			Bulky (Yes/No)			Many Variations (Yes/No)		
Yes/No based on established threshold (Calculated)	Manual Override	Value Used in Calculations	>60 liters (Calculated)	Manual Override	Value Used in Calculation	Calculated (Many Variations if >= 3 options)	Manual Override	Value Used in Calculation
Yes		**Yes**	Yes		**Yes**	Yes		**Yes**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
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No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
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No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	Yes		**Yes**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**
No		**No**	No		**No**	No		**No**

Figure 5. Material classification calculation (1) – one row is one part number

Material Classification Calculations										
AA.1	AA.2	AA.3	AA.4	AB.1	AB.2	AC	C	B	Manual Override	Material Classification
Expensive, Bulky, Many Variations	Expensive, Bulky	Expensive, Many Variations	Other Expensive	Bulky, Many Variations	Bulky	Many Variations	Small (<0,015 liters), Cheap	Normal		
AA.1										AA.1
							C			C
							C			C
							C			C
							C			C
							C			C
							C			C
							C			C
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							C			C
							C			C
							C			C
							C			C
							C			C
						AC				AC
								B	AC	AC
								B	AC	AC
								B		B
								B		B
							C			C
							C			C

Figure 6. Material classification calculation (2) for each part number

Step 8

The form also calculates recommended flow for each class. The green column is the recommended best flow type (see (1) in figure 7). The grey columns include the best flow types in addition to the second/third recommendations. User should input planned flow type.

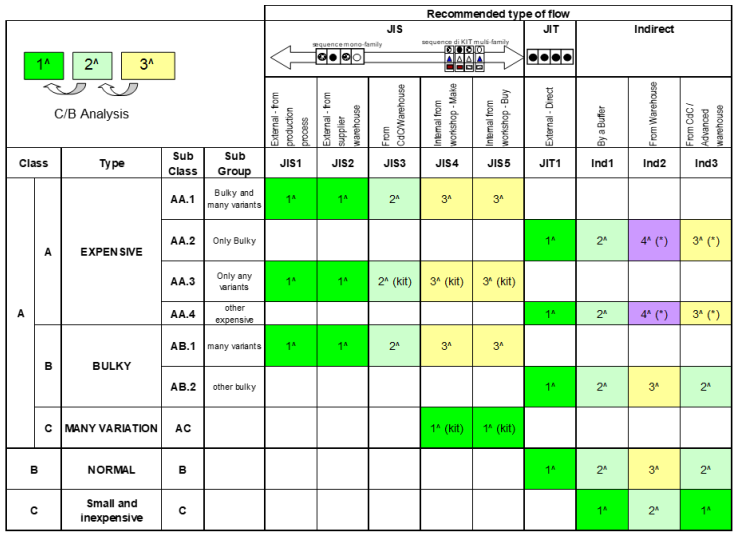
If the flow type is not within the recommended types, the user is flagged and can put a reason for not using the recommended flow (see (2) in figure 7).

3. Summary Charts and Tables

Material Classification per Flow Types matrix is automatically updated based on all inputs. Implementation or modification of a type of flow, must be always supported by Benefit/Cost analysis. Example: If is material in class A1 which is expensive, bulky and many variations, his recommended flow is JIS1/JIS2 (1^), then JIS3 (2^) and finally JIS4/JIS5 (3^) as in figure 8.

Recommended Flow Classification												
Flow Type RECOMMENDED										Flow Type PLANNED (As Is)		
JIS/JIT/ Kanban (Prefered)	JIS1	JIS2	JIS3	JIS4	JIS5	JIT1	Ind1	Ind2	Ind3/4	JIS/JIT/ Kanban	Recommended flow	Reason Not in Recommended Flow
JIS1, JIS2	JIS1	JIS2	JIS3	JIS4	JIS5					JIS1	Yes	
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	P
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	P
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	P
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS1	No	Part of Module
JIS4, JIS5				JIS4	JIS5					JIS4	Yes	
JIS4, JIS5				JIS4	JIS5					JIS4	Yes	
JIS4, JIS5				JIS4	JIS5					JIS4	Yes	
JIT1						JIT1	Ind1	Ind2	Ind3/4	Ind1	Yes	
JIT1						JIT1	Ind1	Ind2	Ind3/4	Ind1	Yes	
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	Ind2	Yes	
Ind1, Ind3/4							Ind1	Ind2	Ind3/4	JIS4	No	Flow better than required

Figure 7. Recommended flow classification



Class		Type	Sub Class	Sub Group	JIS1	JIS2	JIS3	JIS4	JIS5	JIT1	Ind1	Ind2	Ind3
A	A	EXPENSIVE	AA.1	Bulky and many variants	1^	1^	2^	3^	3^				
			AA.2	Only Bulky						1^	2^	4^ (*)	3^ (*)
			AA.3	Only any variants	1^	1^	2^ (kit)	3^ (kit)	3^ (kit)				
			AA.4	other expensive						1^	2^	4^ (*)	3^ (*)
	B	BULKY	AB.1	many variants	1^	1^	2^	3^	3^				
			AB.2	other bulky						1^	2^	3^	2^
	C	MANY VARIATION	AC					1^ (kit)	1^ (kit)				
B		NORMAL	B							1^	2^	3^	2^
C		Small and inexpensive	C								1^	2^	1^

Figure 8. Recommended type of flow

In case of precious materials to keep watch over (see (*) on figure 8). Flows Ind2 and Ind3 can be considered as first choice flow to minimized handling as much as possible.

4. Flow Types

According to Logistics principles production lines are to be fed according to the following main flows types:

- Just in Sequence (JIS)
- Just in Time (JIT)
- Indirect (Ind)

Just in Sequence

Parts are delivered to the line in sequence, according to the sequence of assembly orders launched by production scheduling (“pull”). JIS requires a small buffer, as close as possible to the point of use in the production line (sequenced buffer). However, the buffer is not bigger than the single mean of transport of sequenced containers.

Line feeding arranged by either:

1) Parts of the same logistic family (sequencing)
2) Sets of parts of different logistic families in sequence (kitting)

Just in Time (NOT in sequence)

The quantity of parts delivered to the line is determined by the consumptions of the parts according to the sequence of assembly orders launched by Production scheduling (“pull”).

JIT requires a small buffer, as close as possible to the point of use in the production line (material is not stored in the warehouse). However, the buffer is not bigger than the single mean of transport of containers. Line feeding arranged by single-item container.

Indirect

In this case the material is supplied based on delivery program („push“), where the „In house“ flow is decoupled with the „Inbound“ flow because of a buffer bigger than the single transport.

Recommendations for material flow selection

To reduce stocks and therefore eliminate waste, it is important to adopt a different type of logistic flow depending on the type of material. In implementing the choice of the type of flow, in addition to the aspects indicated above, the constraint of the distance from the supplier with respect to the point of use must be taken into consideration

as well as the cost/benefit assessment of the change in supply flow, making sure to evaluate the total cost based on productivity, quality, handling and distances.

The Decoupled type flow is not good for products with many variants, because to ensure the production line always has the variant it needs, it should has a warehouse for each variant and therefore have a lot of stocks (Vujanac et al., 2017). In this case, a JIT type flow is therefore much better, which is the first choice, because I would produce the variant I need only when I need it and I would not have stocks.

In case the time to produce the required variant is too long, then external or internal sequencing could be used, preferably carried out directly from stock. For normal materials, in assembly lines, the decoupled flow with call via Kanban may be the most suitable.

A different reasoning must be made for small parts (class C), because they do not cost much and are not bulky, so keeping them in stock doesn't cost much; they are also used a lot, so it is not worth ordering and having them shipped every time you need them. In this case, a supply in small boxes in small quantities directly from the warehouse, even following a transfer, is the most suitable solution.

The case of bulky, expensive or normal parts can be handled with a Direct flow. This with the aim of having as little stock as possible: in fact these parts are bulky or expensive and in any case it is expensive to have them in stock, so, as there are not many variants, they can be managed through single-design containers ordered directly from the supplier.

Following the classification of materials, it is possible to identify the match to the ideal flow, that is, the closest to the principles and objectives of the Just In Time system. To allow the achievement of the ideal condition it is advisable to proceed with subsequent optimizations.

Just in sequence 1 (JIS1)

JIS1 is an external build to sequence process at the supplier plant (figure 9). The assembly process sequence drives the supplier production process, in other terms the part is not built until the vehicle is broadcasted to assembly. There is no stock in the plant.

Just in sequence 2 (JIS2)

JIS2 is an external ship to sequence process at the supplier plant from a finished goods buffer (that depends on production mix) in its plant or in its advanced warehouse. It takes place after production process of the supplier. The assembly process sequence drives the picking and loading process at supplier plant and the consequent transport and delivery schedule to the customer.

Just in sequence 3 (JIS3)

JIS3 is an Indirect flow (Supplier sends goods not in sequence). The assembly process sequence drives the picking and loading process at the warehouse area using a kitting or picking area.

Just in sequence 4 (JIS4)

JIS4 is a sequencing activity performed in production area by internal people with material delivered from plant warehouse or temporary storage (Djordjevic et al., 2017).

Just in sequence 5 (JIS5)

JIS5 is a sequencing activity performed in production area by external service provider with material delivered from plant warehouse or temporary storage.

Both of these processes (JIS4/JIS5) could be preceded by a JIT1 or IND1/IND2/IND 3 process, but the part is to be classified with the last flow type used to deliver to point of use.

Just in time (JIT)

In JIT process parts are delivered in the exact quantity according to the consumption (“pull system”) using single-item container. Parts are delivered into specific docks and placed in temporary storage areas close to

usage point. No storage of the parts at the Plant. It is a direct flow from supplier finished products stock to usage point. The total "supply chain Inventory" is very low.

Indirect 1 (IND1)
Parts are delivered to the plant according to a "push" material schedule. Parts are received in a temporary storage area (buffer), then delivered to the line. Material flows from temporary storage area close to point of use applied to single-item containers. The total Supply chain Inventory is higher than in JIT flow.

Indirect 2 (IND2)
Parts are delivered to the plant according to a "push" material schedule. Parts are received and stored in a warehouse within the plant perimeter, then prepared and delivered to the line. Material flows in single-item containers, not delivered in sequence. The total Supply chian Inventory is higher than in IND1 flow.

Indirect 3 an Indirect 4 (IND3/4)
Parts are delivered to the plant according to a "push" material schedule. Parts are received and stored in an external warehouse (consolidation center or advanced warehouse out of the plant perimeter), then prepared and delivered to the line not in sequence. In IND3 process the activities are performed by internal people. In IND4 process the activities are performed by Third party logistics.

5. Results and Discusion

First analysis in the one automotive company showed that 18% or 1225 materials (part numbers) was out of recommended material flow and calculation said that potential waste was more then 250.000 EUR. After two years and several projects new classification of material showed improvements and only 8% part numbers out of recommended material flow as in table 3.

Parts which are distributed in group "out of recommended flow" we can classify in two groups. First one is 6% parts which are in better of recommended material flow (see (1) in figure10) and 2% parts which are in the worse flow as is marked (2) in figure 10.

Reason to put material in better flow usually is request from engineers responsible for workplace organization to reduce or eliminate NVAA (not value add activities).

For some parts is not possible to establish recommended flow like dangerous-explosive materials, and material under special care. Those parts will stay in worse flow.

To install parts in recommended material flow or switch to higher level, flow must always be validated trough Benefit/Cost analysis.

Table 3. Parts distribution according to the recommended levels of material flow

	Levels (1st – the best)				**Out of recommended flow**	**TOTAL**
	1st	**2nd**	**3rd**	**4th**		
Part Number	4552	1451	266	0	524	6793
% of totaly Part Number	67%	21%	4%	0%	8%	100%

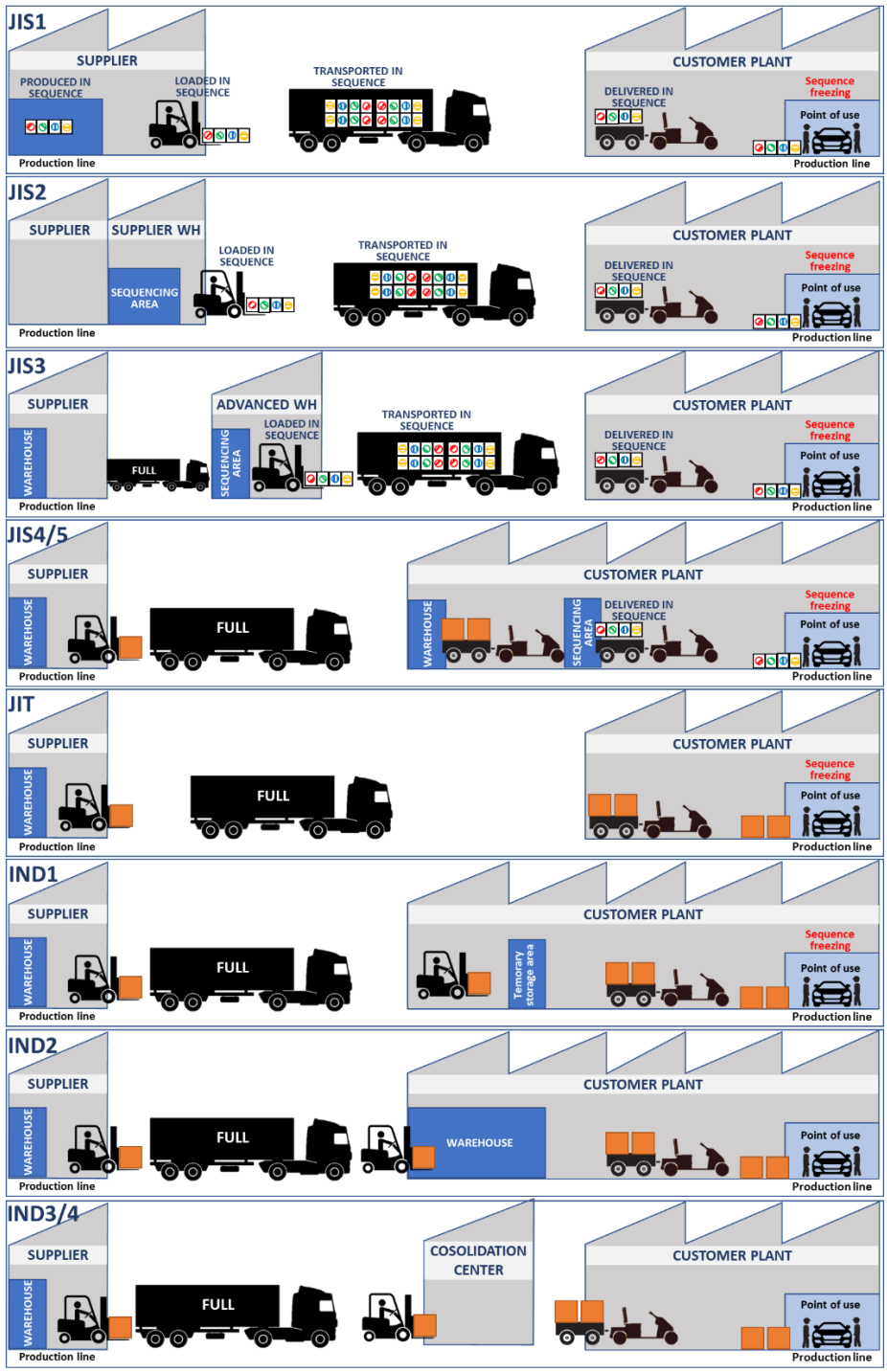
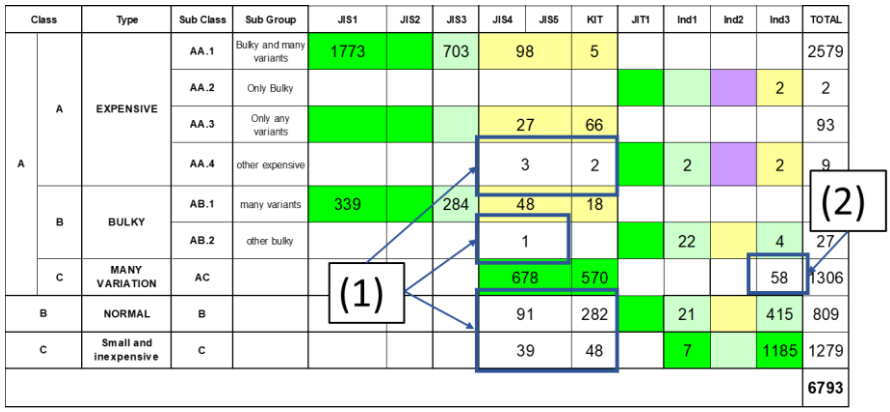


Figure 9. Typical logistics flows in automotive industry



Class		Type	Sub Class	Sub Group	JIS1	JIS2	JIS3	JIS4	JIS5	KIT	JIT1	Ind1	Ind2	Ind3	TOTAL
A	A	EXPENSIVE	AA.1	Bulky and many variants	1773		703	98		5					2579
			AA.2	Only Bulky										2	2
			AA.3	Only any variants				27		66					93
			AA.4	other expensive				3		2		2		2	9
	B	BULKY	AB.1	many variants	339		284	48		18					
			AB.2	other bulky				1				22		4	27
	C	MANY VARIATION	AC					678		570				58	1306
B		NORMAL	B					91		282		21		415	809
C		Small and inexpensive	C					39		48		7		1185	1279
															6793

Figure 10. Result in summary chart: part number distribution in order to recommended flow

6. Conclusions

Logistic generate big cost in company, especially in automotive industry, where we operate with more than 10.000 part numbers. In this article we presented methodology how to establish the best material flow in order to characteristics of material. If we know dimensions, cost of material and number of variations in one logistic family, with presented methodology is possible to classify each material.

First is necessary to define limits: minimum volume to part categorize as bulky, minimum price to decide that part is expensive a minimum number of variations (usually is 3) of parts in one logistic family.

Then, application automatically classify each part number and recommended material flow for each one.

At the end, application analyze recommended and actual material flow, prepare gap analysis, and prepare reports. This is start point for new project opening to reduce logistics cost and eliminate waste.

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References:

Bartolacci, M. R., LeBlanc, L. J., Kayikci, Y., & Grossman, T. A. (2012). Optimization modeling for logistics: Options and implementations. *Journal of Business Logistics*, *33*(2), 118–127. https://doi.org/10.1111/j.0000-0000.2012.01044.x

Brdulak, J., & Zakrzewski, B. (2013). Methods for calculating the efficiency of logistics centres. *Archives of Transport*, *27–28*(3–4), 25–43. https://doi.org/10.5604/01.3001.0004.0106

Bulatovic, M. (2013). *Logistics.* Chamber of Engineers, Podgorica.

Davidovic, B. (2012). *Intralogistics.* Intelekt, Belgrade.

Djordjevic, M., Vujanac, R., & Rajkovic, D. (2017). Kitting as the way of human error elimination. *Quality Fest Proceedings,* 195-202.

Doerr, K. H., Mitchell, T. R., Klastorin, T. D., & Brown, K. A. (1996). Impact of material flow policies and goals on job outcomes. *Journal of Applied Psychology*, *81*(2), 142–152. https://doi.org/10.1037/0021-9010.81.2.142

Goldsby, T., & Martichenko, R. (2005). *Lean six sigma logistics.* J. Ross publishing, Plantation.

Ha, B., Park, Y., & Cho, S. (2011). Suppliers' affective trust and trust in competency in buyers: Its effect on collaboration and logistics efficiency. *International Journal of Operations & Production Management*, *31*(1), 56–77. https://doi.org/10.1108/01443571111098744

Han L. N., Ma X. Z., Tan J. D., Li, J. H., Dong Y. Q. (2023). Balancing Material Supply-Demand with ARIMA and Neural Networks. *Int. Journal of Simulation Modelling, 22*(4), 712-722. . https://doi.org/10.2507/IJSIMM22-4-CO18

Kovács, G. (2018). Methods for efficiency improvement of production and logistic processes. *Research Papers Faculty of Materials Science and Technology Slovak University of Technology*, *26*(42), 55–61. https://doi.org/10.2478/rput-2018-0006

Narciso, M., Piera, M. A., & Guasch, A. (2010). A methodology for solving logistic optimization problems through simulation. *SIMULATION*, *86*(5–6), 369–389. https://doi.org/10.1177/0037549709356011

Rahimi, Y., Matyshenko, I., Kapitan, R., & Pronchakov, Y. (2020). Organization the information support of full logistic supply chains within the industry 4. 0. *International Journal for Quality Research*, *14*(4), 1279–1290. https://doi.org/10.24874/IJQR14.04-19

Regodic, D. (2014). *Logistics – supply chain.* University Singidunum, Belgrade.

Sendra, C., Gabarrell, X., & Vicent, T. (2007). Material flow analysis adapted to an industrial area. *Journal of Cleaner Production*, *15*(17), 1706–1715. https://doi.org/10.1016/j.jclepro.2006.08.019

Vujanac, R., Djordjevic, M., & Blagojevic, M. (2015). Mechanical LCA system in Production and Assembly. *The 3rd International Conference Mechanical Engineering in XXI Century Proceedings*, 439-442.

Vujanac, R., Djordjevic, M., & Miloradovic, N. (2017). Semi-automatic mechanical transport-handling system for production and assembly lines. *Proceedings of the XXII International Conference MHCL 2017*, 173-176.

Wong, W. P., Soh, K. L., Chong, C. L., & Karia, N. (2015). Logistics firms performance: Efficiency and effectiveness perspectives. *International Journal of Productivity and Performance Management*, *64*(5), 686–701. https://doi.org/10.1108/IJPPM-12-2013-0205

Milan Đorđević
Academy of applied studies
Sumadija,
Kragujevac,
Serbia
mdjordjevic@asss.edu.rs
ORCID 0000-0001-5941-3262

Sonja Kostić
Academy of applied studies
Sumadija,
Kragujevac,
Serbia
skostic@asss.edu.rs
ORCID 0000-0002-6120-6139

Hrvoje Puškarić
Academy of applied studies
Sumadija,
Kragujevac,
Serbia
hpuskaric@asss.edu.rs
ORCID 0000-0002-9239-1867

Rodoljub Vujanac
University of Kragujevac,
Faculty of Engineering,
Kragujevac,
Serbia
vujanac@kg.ac.rs
ORCID 0000-0002-8215-5668

Srđan Atanasijević
Endava,
Kragujevac,
Serbia
srdjan.atanasijevic@kg.ac.rs
ORCID 0000-0003-4414-1799

Maja Đorđević
Siemens,
Kragujevac,
Serbia
maja.djordjevic@siemens.com
ORCID 0009-0004-0756-5546