The CO_2 management decision problem in tactical sales planning of light commercial vehicle manufacturers in Europe

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Abstract: In this paper, the question of how trade-offs between contribution margins and CO_2 fleet emissions could be managed within tactical sales planning of light commercial vehicle manufacturers in the EU is addressed. We develop a planning framework to derive optimal sales plans from both an ecological and environmental perspective, considering constraints such as available production and logistics capacities as well as market demand. Based on the framework, we analyse how alternative sales plans on the level of models, variants, and equipment options with similar contribution margins can lead to very different outcomes with respect to CO_2 fleet emissions and vice versa. The results of this study indicate that sales planning with a detailed view on CO_2 emissions is essential to ensure profitability of light commercial vehicle manufacturers until zero emission vehicles achieve competitive contribution margins and substantial market shares.

Keywords: CO_2 fleet emissions; CO_2 management; volume planning; installation rate planning; automotive sales management; sales and operations planning.

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1 Introduction

In the European Union, manufacturers of light commercial vehicles (LCVs) face the challenge to comply with the CO_2 fleet emission targets. A manufacturer's fleet consists of all delivered vehicles within a calendar year. Similar to passenger cars, the individual CO_2 targets are based on the average weight of the manufacturers' vehicle fleet (EUP&C, 2019).[1] An excess emissions premium of €95 must be paid for every gram of exceedance and vehicle sold, decreasing the profitability. LCV targets announced for 2025 and 2030 in the EU are considered as 'extremely demanding' by the European Automobile Manufacturers' Association (ACEA, 2022a). As part of the 'green deal' and the 'fitfor55' initiative, even stricter targets must be expected.

LCV manufacturers undertake strategic investments to electrify their vehicle portfolios within the next decades. During this transition phase from combustion engine vehicles towards zero emission vehicles, however, manufacturers need to make decisions on the composition of their vehicle fleets subject to the available technologies. These decisions must be in line with the current legislation and at the same time allow for the financing of the expensive transformation.

In the short- to mid-term, the tactical sales planning defines the relevant characteristics of a manufacturer's vehicle fleet in terms of CO_2 emissions and profitability. The decision on the sales quantity of certain models, variants, and optional equipment is usually based on the overriding objective of maximising profit. With the EU CO_2 legislation, meeting the CO_2 targets is becoming increasingly important.

European manufacturers operating in a build-to-order environment, typically offer a large variety of customer-individual configuration options that lead to unique customer specifications and a wide range of plannable variants. A plannable variant is defined as the combination of a certain model and an additional set of specified vehicle characteristics and selected optional equipment items. According to the European CO_2 legislation, every vehicle configuration must be considered with an individual CO_2 value for the average fleet emissions. All optional equipment items with an influence on the weight, the frontal area, or the rolling resistance must be considered when estimating the specification-individual CO_2 value.

When deciding on the quantities of each plannable variant, sales planning needs to trade off profits and CO_2 compliance. We refer to this conflict of objectives as the CO_2 management decision problem. Selling vehicles without local emissions, such as battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs), helps to meet CO_2 targets. Plug-in hybrid electric vehicles (PHEVs) have a positive effect as well. Profit maximisation can be achieved by increasing the sales volumes of highly equipped ICEVs, which currently have the highest contribution margins. According to McKinsey (2023) the profitability of current BEV models is slightly above breakeven for the majority of manufacturers. Also, FCEVs and PHEVs are not as profitable as ICEVs yet

(McKinsey, 2021; Cano et al., 2018). Due to specification-individual CO_2 values, especially highly equipped vehicles have a negative effect on the manufacturers CO_2 fleet emissions, leading to excess emissions premiums. In turn, optional equipment has a substantial impact on a vehicle's contribution margin (Temur, 2021).

For LCV manufacturers, meeting the CO_2 fleet targets is even more challenging than for passenger car manufacturers. Firstly, for several technological and economic reasons, the market share of electric LCVs is still lower compared to passenger cars and has increased substantially slower in recent years (EEA, 2021; ACEA, 2022b).[2] From a technological point of view, important characteristics such as payload, towing capacity, cargo space, and range of BEVs are not yet competitive compared to ICEVs (Buchenau, 2022; ACEA, 2018). From an economical point of view, lower sales volumes and contribution margins, as well as longer development cycles lead to a later electrification of the LCV fleets (ACEA, 2018). Secondly, the global shortage of batteries and semi-conductors restricts the production capacities of BEVs (Jato Dynamics, 2022; Roland Berger, 2021). This is particularly difficult for LCV manufacturers organised in multi-brand groups (e.g., Mercedes Benz Vans or Volkswagen Commercial Vehicles), where scarce parts are first allocated to premium passenger cars brands for reasons of profitability (Hubik and Tyborski, 2023). Therefore, solving the CO_2 management decision problem by increasing sales of zero emission LCVs is limited in the short and medium term.

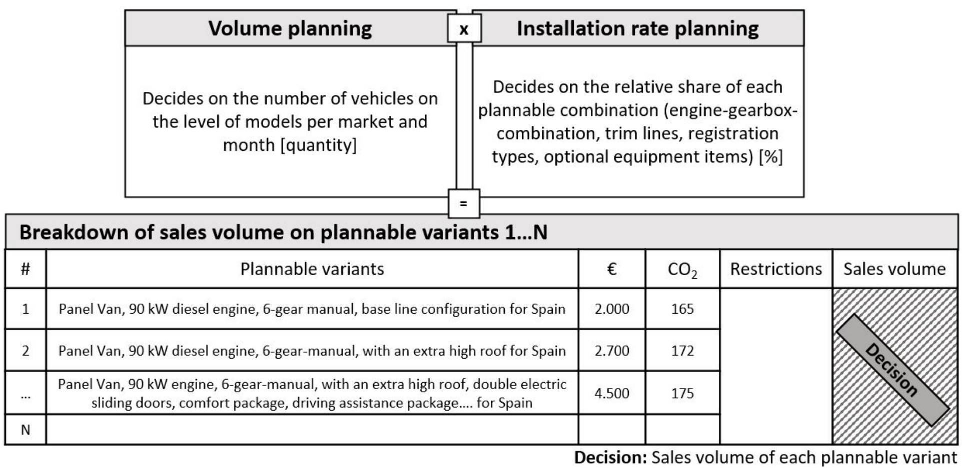
In addition, the CO_2 management for LCV manufacturers is more complex due to the different registration types. The EU CO_2 legislation is divided into the registration types M1 (passenger cars) and N1 (LCVs) registrations, both of which are served by manufacturers – usually with the same base vehicle. N1 vehicles are allowed to emit slightly more CO_2 than M1 vehicles. For LCV manufacturers, complying with CO_2 targets in the M1 class is considered a major challenge due to the great importance of ICEVs. The typical product portfolio of these manufacturers usually includes additional vehicles with camper van and special purpose registrations (M1-SP, N1-SP) as well as vehicles over 3.5 tons (M2, N2), which are not included in the calculation of fleet emissions. Thus, depending on the exact specification, an LCV can be either relevant or irrelevant to CO_2 fleet emission considerations.

We develop a framework to support tactical sales planning in solving the CO_2 management problem when deciding on sales quantities. The framework is applied to a sample manufacturer to illustrate the trade-off between profitability and CO_2 compliance considerations. The remainder of this article is structured as follows: in Section 2, a detailed overview of the CO_2 management problem in tactical sales planning is provided, and requirements for a decision framework are derived. Section 3 comprises a literature review. The new framework for tactical sales planning is presented in Section 4 and applied to an illustrative case study in Section 5. Concluding remarks are given in Section 6.

2 CO_2-oriented tactical sales planning of LCV manufacturers

Tactical sales planning for LCV manufacturers usually consists of two core tasks (Uhlich and Kieckhäfer, 2023): volume planning and installation rate planning (Figure 1). Since the anticipation of exact specific customer orders is not possible, planning processes are carried out on an aggregated level (Volling, 2009). Volume planning decides on the quantity of vehicles on the level of models (e.g., the Mercedes Benz Vito) per sales market (e.g., Spain) and month. Installation rate planning, in turn, determines the relative shares of certain engine technologies (e.g., ICE), registration types (e.g., M1), trim lines (e.g., Vito Tourer PRO), engine-gearbox combinations (e.g., 150 kW diesel engine, automatic transmission and four-wheel drive), roof types (e.g., regular roof), and relevant optional equipment (e.g., power sliding doors). These equipment options are often referred as 'heavy items' in practice. They have a substantial influence on capacity management, CO_2 values, and contribution margins. Together, the volume planning and installation rate planning determine the sales volume of each possible combination of vehicle specifications. These decisions define the relevant characteristics of a manufacturer's planned vehicle fleet in terms of profitability and CO_2 emissions.

Figure 1 Volume and installation rate planning as subtasks of tactical sales planning for manufacturers of LCVs



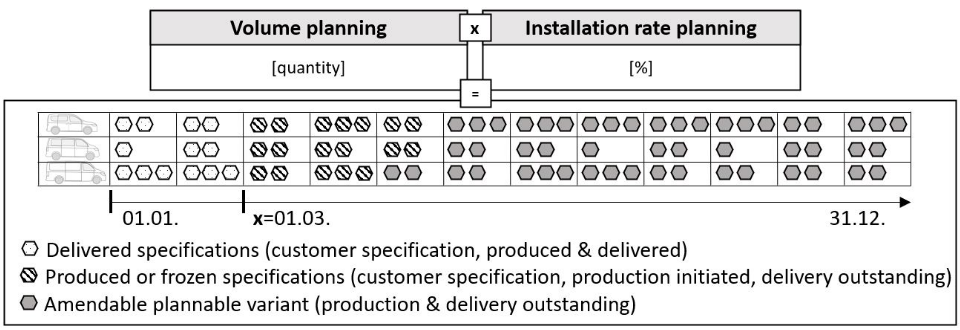
European LCV manufacturers mainly pursue a build-to-order (BTO) strategy with a smaller share of build-to-stock (BTS) as a second fulfilment strategy (Volling et al. 2013). From an OEM's perspective, both types of orders are treated equally as also stock orders are placed and specified by dealerships or national sales companies. For BTO production systems, the development, procurement, and the manufacturing of components are based on order-independent planning (push-based). Processes after the decoupling point such as the assembly or distribution are directly linked to individual orders (pull-based) (Volling et al., 2013). The tactical sales plan defines in advance how many parts or components will be needed at which point of time to fulfil the planned demand. From a short-term production program planning perspective, this means that, e.g., 10% of all produced vehicles within one production week can have an 'electric rear door closing system', but it does not define which individual customer order includes this item. However, in this article, we focus on the sales planning perspective. The resulting available capacities are matched with individual customer orders. If a desired item within an order is not available at the desired point of time, the order cannot be produced and is shifted into the future (with the risk of cancellation or customer dissatisfaction).

The decision space in tactical sales planning is restricted by two aspects: possible production and logistics capacities on the one hand and market demand on the other.

These restrictions are based on estimations and uncertain forecasts. Therefore, coping with changing information over time is important. For example, the COVID-19 pandemic, and the war against Ukraine disrupted global supply chains in recent years, and market demand exceeded available production capacity (McKinsey, 2022). Yet, experts see the market demand dropping from 2023 onwards due to recession threats (Menzel, 2022).

Tactical sales planning usually has a rolling planning horizon of 12 to 24 months and is carried out monthly. In the planning process, the sales plans are updated by specific customer orders (specifications) when being received (Lim et al., 2017). With every iteration the quantity of plannable variants within the sales plan of a specific year decreases and the number of individual specifications increases (see Figure 2). As more vehicles are produced and delivered to customers throughout the year, tactical sales planning loses its influence on the composition of the vehicle fleet and on the achievement of the company's objectives.

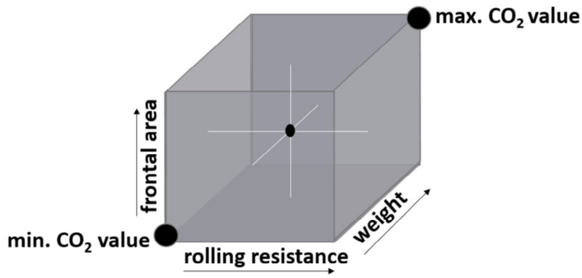
Figure 2 Tactical volume and installation rate planning defining the manufacturers vehicle fleet



Each plannable variant or specification has its individual CO_2 value. To determine the CO_2 value of millions of different possible vehicle configurations, manufacturers use mathematical interpolation families derived by physically testing certain vehicles on a roller test bench in accordance with the WLTP standard. Based on these interpolation families, consisting of two vehicles, one with a very high and one very low CO_2-value, individual values for each configuration are estimated (ICCT, 2020). A vehicle of an interpolation family without additional equipment (shown as a minimum CO_2 value in Figure 3) can be converted to a vehicle with a higher CO_2 value by adding configuration elements that increase the frontal area (e.g., a high roof), change the rolling resistance (e.g., different tires) or increase the weight (e.g., an additional seat) until the maximum CO_2 value of the family is reached.

The EU has defined general CO_2 fleet targets of 147 g/km for N1 vehicles with a reference weight of 1,766.4 kg and 95 g/km for M1 vehicles with a reference weight of 1,379 kg M1, respectively. The individual target of a manufacturer is influenced by the average weight of the fleet within one registration class. With every additional kilogram of weight, vehicles with an M1 registration may emit 0.0333 grams of CO_2 more. For N1 registrations, this slope factor is 0.096. In addition, 2020 figures such as the average weight, CO_2 values, and the CO_2 targets of each registration type are relevant for the calculation of the specific fleet target of the current year (EUP&C, 2019).[3]

Figure 3 Calculation of vehicle individual CO_2 value based on frontal area, weight, and rolling resistance



Source: Uhlich and Kieckhäfer (2023)

To meet CO_2 fleet emission targets within tactical sales planning, a variety of measures is available: amongst others, the average CO_2 emission value of the vehicle fleet can be reduced by increasing sales volume of variants with BEV, PHEV, and FCEV technology. Additionally, ICEVs with small engines and few optional equipment lower the average CO_2 value. However, these products cannot yet match the contribution margins of fully equipped ICEVs, resulting in a trade-off between CO_2 reduction and profit maximisation. As an additional lever, the share of variants with individual (over-)achievement of the CO_2 target can be increased. Also, the CO_2 target can be increased by allocating the volume to sales markets where, on average, customers choose options with high additional weight but low additional CO_2 emissions. Shifting sales volumes to the registration types with a less stringent target (e.g., M1 to N1) or to registration types not included in the CO_2 regulation (e.g., M2, N2, M1-SP, N1-SP, and camper) is a further measure.

3 Literature review

In the following, existing approaches from recent literature will be presented, covering general concepts from sales and operations planning (S&OP) as well as automotive-specific optimisation models.

3.1 Sales and operations planning

The decision problem presented above is related to the literature stream of S&OP. A review of decision making models in this area is presented by Pereira et al. (2020). Generally, S&OP aims to define a cross-functional plan coordinating decisions in the areas of procurement, production, distribution, and sales (Pereira et al., 2020; Thomé et al., 2016). On a tactical horizon, sales planning is usually linked to production program planning and is often referred as extended production planning (Pereira et al., 2020; Grimson and Pyke, 2007). Constraint-based planning and optimisation play an important role in this field of research (Pereira et al., 2020). While most S&OP optimisation problems follow a single objective (e.g., maximise profits or minimise total costs), few publications include environmental considerations (e.g., Attia et al., 2019; Fahimnia et al., 2015; Meisel et al., 2013; summarised in Pereira et al., 2020).

Within S&OP, special consideration is given to demand selection decisions and approaches to cope with variability and uncertainty of information. Demand selection decisions are particularly important when the expected demand exceeds the available production and logistics capacities. *Order acceptance* strategies decide on a certain set of orders (or sales potential) that should not be satisfied to select the most profitable demand in each period. *Sales backlogging* strategies pursue a postponement of less profitable orders to subsequent periods (Pereira et al., 2020). Most models in this field take decisions on the level of product families (summarising several models or variants) to reduce complexity (Pereira et al., 2020; Feng et al., 2013). Some models differentiate between customers (Nemati and Alavidoost, 2019) or sales regions (Ben Ali et al., 2019).

Variability, uncertainty considerations, and generally changing information play an essential role in S&OP. Especially production capacities (e.g., Aouam and Brahimi, 2013; Feng et al., 2013) and demand (e.g., Hahn et al., 2016; Feng et al., 2013; Shahi et al., 2017; Aouam and Brahimi, 2013) are subject to possible changes over time (*variability*). *Uncertainty* is mainly related to demand information. Mathematical optimisation models in the field of S&OP address uncertainty by using fuzzy, stochastic, or sometimes robust programming (Pereira et al. 2020). To cope with uncertain and gradually *changing information* in a deterministic way, rolling planning is a popular method. In the automotive industry, this is especially applicable for manufacturers with a large variety of product variants and a build-to-order production process. The deterministic planning is carried out on an aggregated level because predicting actual customer orders and their individual characteristics is not possible. The realisation of actual orders and their effect on the achievement of a company's goals can be reflected in the next rolling planning execution (Volling, 2009).

3.2 Approaches for the automotive industry

CO_2 reduction in the automotive industry has become increasingly popular in the scientific literature in recent years. Especially related to our planning problem are papers dealing with assortment planning and strategic portfolio planning.

In the field of automotive assortment planning, Umpfenbach et al. (2018) optimise product lines with the overall goal of profit maximisation while complying with the US CO_2 emissions regulation. They decide on production numbers on the level of variants within one period. Actual sales figures during a period are not considered. CO_2 emissions during the use phase are modelled as average values on the level of engine-gearbox-variants. CO_2 emissions arising from production and logistics are regarded on a detailed level, covering also trim lines and several optional equipment (e.g., electrical consumers). Constraints in terms of production and logistic capacities are particularly reflected on the level of core components. Taghavi and Chinnam (2014) present a similar optimisation model. To comply with the CO_2 regulations, demand for certain variants in several markets does not have to be met. Maddulapalli et al. (2012) seek to maximise contribution margins while fulfilling the US fleet emissions target. In the paper, manufacturers are considered offering similar models with different brands based on the same platform.

In the area of strategic portfolio planning, Thies et al. (2022) maximise the net present value of a project portfolio on the level of models with alternative powertrain technologies. In the objective function, penalties for a possible CO_2 target exceedance based on the European legislation are considered. The CO_2 target, however, is set exogenously and independent of the fleet's average characteristics. Raasch et al. (2007) decide on the realisation of vehicle projects, considering different model groups, partly variants, and optional equipment following mainly financial objectives. CO_2 emissions are set as average values on the model group level. Kreuz (2022) focuses on decisions related to the deployment of technological measures to reduce CO_2 emissions. The objective is to comply with CO_2 targets with minimal additional costs per vehicle. The European CO_2 legislation is modelled in detail, covering aspects such as eco innovations or super credits.

In addition, Biller and Swann (2006) consider different pricing decisions in the short- to mid-term planning in order to achieve CO_2 targets. Ibrahim et al. (2021) present an optimisation model to reduce CO_2 management costs with four decision options: investing in CO_2 technology, paying CO_2 tariffs for non-compliance, restricting sales, or reconfiguring vehicle features. Bersch et al. (2021) evaluate strategic trade-offs for the resource-constrained market introduction scheduling to fulfil CO_2 fleet targets. Whitefoot and Skerlos (2012) decide on vehicle footprints, acceleration, technology aspects, and the price while seeking profit maximisation. The decision is constrained by footprint-based fuel economy targets defined by the US CAFE regulation. Michalek et al. (2004) optimise long-term decisions regarding product prices, product designs, and production volumes in order to maximise profit while considering CO_2 penalties.

3.3 Evaluation of the literature

None of the presented approaches is fully capable to support the CO_2 management decision problem in tactical sales planning of LCV manufacturers in Europe. The group of planning approaches in S&OP generally fulfils the basic requirements of tactical sales planning in the automotive industry, especially related to demand selection. However, CO_2 fleet emission regulations or the trade-off between CO_2 emissions and profitability are not reflected.

To some extent, these aspects are included in articles with a specific focus on the automotive industry. The group of strategic portfolio planning approaches (e.g., Thies et al., 2022) consider long-term decisions and are therefore limited in their applicability to our problem. Assortment planning models such as the one presented by Umpfenbach et al. (2018) fall somewhat in-between the tactical S&OP and strategic portfolio planning approaches. These models deliver valuable insights how to cover different vehicle variants and optional equipment as well as constraints related to CO_2 emissions and supply capacities.

Overall, the full complexity of tactical sales planning in LCV manufacturing is not considered in any paper. On the one hand, this holds for the necessary level of disaggregation related to markets, registration types, models, variants, trim lines, and optional equipment items. On the other hand, no attention is given to actual sales figures or characteristics of already produced vehicles for the upcoming planning period.

For these reasons, we develop a new framework for tactical sales planning of LCV manufacturers that considers the CO_2 management problem. The framework will build up on single aspects of the above presented approaches, such as the decision options presented in Ibrahim et al. (2021), the rolling planning horizon approach as presented in Volling (2009), and the ideas of Umpfenbach et al. (2018) how to consider CO_2 emissions and supply constraints.

4 Development of a new framework for CO_2-oriented sales planning

The novel framework to support the CO_2 management problem in tactical sales planning, presented in Figure 4, is based on Uhlich and Kieckhäfer (2023).

At the centre of the framework is the decision on the sales volume of each plannable variant for a specific year, considering the trade-off between maximising contribution margins and reducing CO_2 emissions. The decision on the sales volume is derived by combining the tasks of volume planning and installation rate planning. It is constrained by market demand, production capacities, and parts supply. While a global production constraint may limit the total production capacity of all plants for all models to a certain number, other constraints may be very granular, limiting the supply of parts for a specific option. The same variance in granularity applies to forecasted sales demand. Following Pereira et al. (2020), demand selection and sales backlogging approaches are considered to derive a feasible sales plan in line with the constraints and the objective guiding tactical sales planning.

The specific objective to be pursued may vary from automaker to automaker. Therefore, the framework includes four alternative objective functions (top left part in Figure 4):

1 minimise the nominal CO_2 value

2 reduce the deviation from resulting CO_2 targets

3 maximise contribution margins

4 maximise contribution margins after deducting the CO_2 excess emissions premium.

Some of the provided objective functions have questionable ethical implications, especially when purely focusing on the maximisation of contribution margins. We strongly suggest manufacturers to decrease their nominal CO_2 emissions at least to the legally required level. This would also be in favour of the reputation of the company. However, reducing CO_2 emissions must be done in an economically sensible way.

Tactical sales planning relies on input data (top middle part). Product portfolio data is needed to define the available plannable variants at the level of different models, engine technologies, registration types, trim lines, roof types, and selected optional equipment (heavy items) per sales market. For these variants, data on average CO_2 emissions, weights, and contribution margins is required. The same applies to the vehicle specifications already delivered to customers in the current year (actual sales). In addition, information on the current CO_2 legislation and relevant parameter values from previous years must be included in the planning process to ensure the correct determination of the CO_2 target.

Tactical sales planning is executed at a specific point in time. On the one hand, the resulting sales plan condenses the decisions on the sales volume of each plannable variant (lower left area of the framework, marked as dark grey). These decisions can still be changed. On the other hand, the plan includes vehicle specifications that have already been delivered and specifications in the frozen horizon of production planning. Both can no longer be influenced by tactical sales planning (Lim et al., 2017). Only the point of time of the actual delivery to a customer may vary due to external circumstances. As explained earlier, the characteristics of these specifications in terms of CO_2, weight, and contribution margin are considered as relevant input data in the framework.

Figure 4 Framework for the CO_2 management decision problem in tactical sales planning

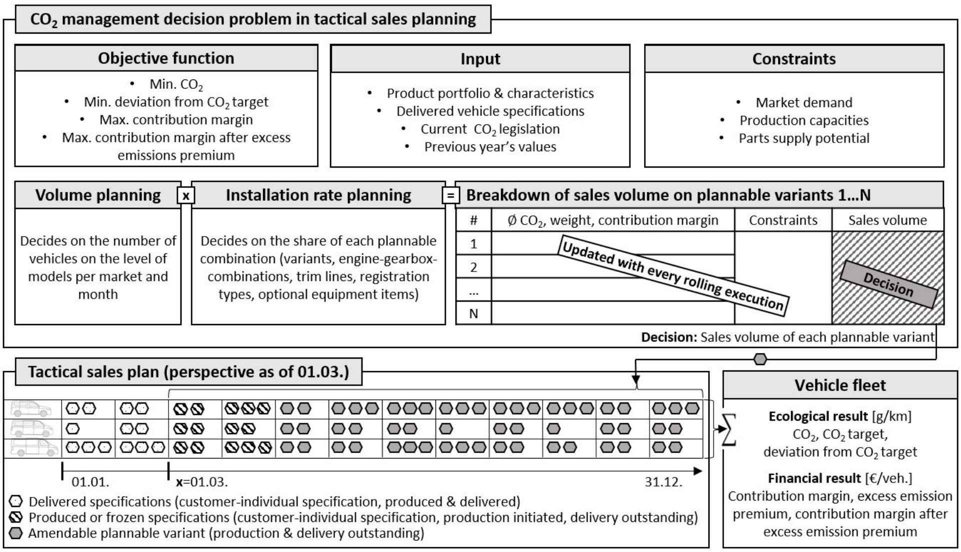
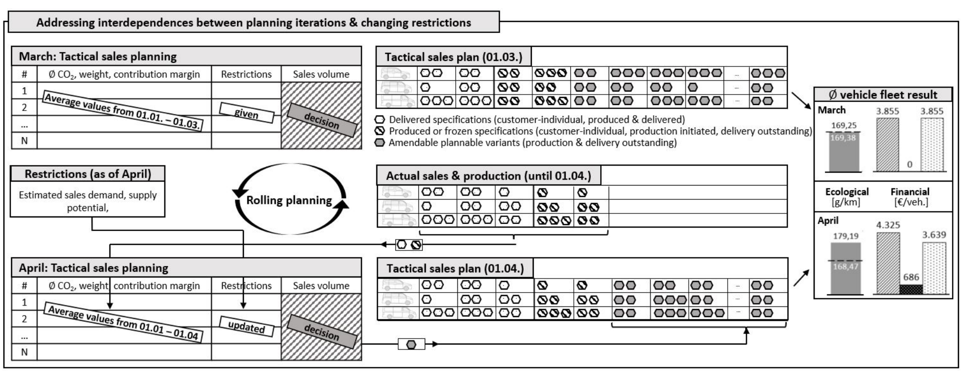


Figure 5 Application of the framework as a rolling planning approach to include changing restrictions and interdependencies of succeeding planning executions within a year



The tactical sales plan represents the vehicle fleet of an entire year. Therefore, decisions on the sales volume of the plannable variants directly influence the environmental and financial performance indicators (lower right part of Figure 4). From an environmental perspective, the most relevant metrics are the fleet's CO_2 emissions and the deviation from the fleet's CO_2 target. From a financial perspective, the average contribution margin per vehicle with and without the CO_2 excess emissions premium are important indicators.

Given that demand forecasts as well as production and supply capacities are uncertain and subject to change, the tactical sales plan must be updated in a rolling planning horizon, as shown in Figure 5. The figure illustrates a March 1st sales plan and an April 1st sales plan, including the financial and environmental impacts of these plans. With every rolling execution, the latest available information can be incorporated into the planning process. In addition to forecast updates, actual deliveries to customers and production of customer specifications from the previous month are highly relevant.

Average values of these specifications are used as input data to refine the corresponding characteristics of each plannable variant. Also, country-specific take rates for optional equipment beyond a plannable variant can be included. This increases the accuracy of each plannable variant for future specifications. Moreover, the rolling execution of tactical sales planning provides regular opportunities to initiate countermeasures if actual sales and production figures deviate from the plan and negatively impact the achievement of specific targets (e.g., CO_2 fleet emissions as of December 31st).

5 Illustrative applications

In the following, the novel planning framework is applied to an illustrative case study of an LCV manufacturer facing the 2023 European CO_2 legislation. Subsection 5.1 summarises the key data and assumptions of the case study. Based on the alternative objective functions included in the framework, four different sales plans are derived and compared for the sample manufacturer as of March 2023 (Subsection 5.2). We repeat this procedure for a planning round in July to demonstrate the effect of the rolling planning approach (Subsection 5.3). The results are discussed in Subsection 5.4.

5.1 General scenario definition

The LCV manufacturers' portfolio consists of four different model groups in the transporter A segment (e.g., Renault Kangoo), B segment (e.g., Ford Tourneo) and C/D segment (e.g., Mercedes Benz Sprinter) as well as a pick-up (e.g., Toyota Hilux). The manufacturer offers variants with ICE, BEV, and PHEV technology in only three illustrative sales markets. Different trimlines with a certain set of mandatory and optional equipment items are considered. Variants with N1, M1, special purpose vehicle, and camper van registrations are available. For our illustrative scenario, this results in a complexity of 74 plannable variants. Further details, such as contribution margins or CO_2 figures, can be found in Table A1. Industry experts were consulted to derive a representative but fictive set of values for this demonstration purpose.

For the case study, we consider the manufacturer's situation as of March 1st with the following assumptions: at this point of time, 4,600 specifications have been delivered to customers, representing 15% of the planned full year sales volume. Further 15% of all vehicles are in the frozen area of the planning horizon, leaving 70% of the full year plan amendable. An initial tactical sales plan delivers a first distribution of the remaining full year sales volume on plannable variants. This is referred as 'baseline scenario' in the following. The maximum possible sales potential as well as the restrictions in terms of production and logistics capacities of each plannable variant are known. For simplification purposes, we assume that an increase or decrease of each plannable variant's sales volume by 40% compared to the initial planning is possible. The complexity of restrictions arising from real world production networks are much more complex. The overall full year volume shall remain constant. The shifting of sales volumes between registration types, models, powertrain technology, sales markets, or variants with certain optional equipment options is possible within the specified limits.

To determine realistic CO_2 targets in line with the latest legislation in Europe (EUP&C, 2019), further technical assumptions are made. These include the manufacturer's historical fleet values for 2020, covering weight, CO_2 target, CO_2 average values (both calculated using the NEDC and WLTP standard)[4], and a reference weight (M0) based on previous years. All assumptions and applicable equations are summarised in Table 1. Further mechanisms of the CO_2 regulation, such as eco innovations, super credits, and phase-in are not considered.

Based on these assumptions, the initial sales plan in the baseline scenario consists of a vehicle fleet with an average weight of 1,933 kg. The combined CO_2 target for the M1 and N1 vehicles is 170.6 g/km. With an average CO_2 value of 179.6 g/km, the target is missed by 9.6 g/km. The resulting excess emissions premium of €829 per vehicle reduces the contribution margin per vehicle from €6,096 to €5,267.

Table 1 Input parameter and formulas for the calculation of CO_2 fleet targets according to EUP&C (2019) and scenario specific assumptions

Input parameter (EUP&C, 2019)	*M1*	*N1*
WLTP $CO_{2\,2020}$	186 g	208 g
NEDC $CO_{2\,2020}$	154 g	174 g
NEDC CO_2 $target_{2020}$	107 g	166 g
$M0_{2020}$ (reference weight)	1,379.88 kg	1,766.4 kg
$M0_{2023}$ (reference weight)	1,390 kg	1,820 kg
MRO_{2020}	1,778 kg	1,967 kg
MRO_{2023} (for N1 or M1)	$MRO_{2023} = \frac{\sum \text{vehicle weight}}{\text{full year sales volume}}$	
Slope factor (SF)	0.0333	0.096
Equations (EUP&C, 2019)	*M1*	*N1*
RT CO_2 (for N1 or M1) reference target with translation	$RT\ CO_2 = \frac{\text{NEDC } CO_2 \text{ target}_{2020}}{\text{NEDC } CO_{2\,2020}}$	

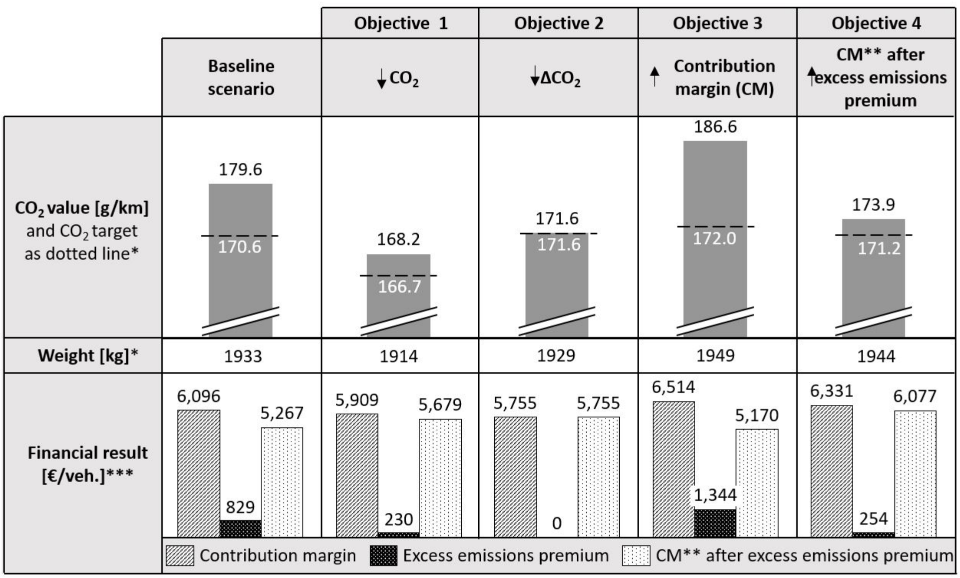
Notes: MRO = mass in running order (weight); NEDC = new European driving cycle; WLTP = worldwide harmonised light duty vehicle testing procedure; RT = reference target with translation.

5.2 March tactical sales planning

To derive the tactical sales plans as of March for the alternative objective functions included in the planning framework, we apply a simple heuristic: The available plannable variants are sorted according to their individual contribution to a specific objective function (e.g., starting with the lowest CO_2 value). The sales volume of the variant ranked first is increased first, while the sales volume of the variant ranked last is reduced, considering the individual constraints. By sorting and re-planning, selected demand is accepted while other is postponed to later months outside the planning period or is not satisfied at all. This approach results in four new sales plans, which differ in terms of their fleet composition and the relevant financial and environmental indicators (see Figure 6).

The reduction of the nominal CO_2 value leads to a sales plan with a maximum share of BEV and PHEV models and a higher share of ICEVs in the A segment compared to the B and C/D segments. Within each segment, the sales volume of variants with few additional options and smaller engines is higher than before. Variants with high performance engines or characteristics that lead to high CO_2 emissions are avoided. In addition, the resulting sales plan is also characterised by a reduced CO_2 target. This effect is due to a reduction in the average weight of the fleet. Vehicles in the B and C/D segments are significantly heavier than those in the A segment. The overall fleet target deviation is reduced to 3.4 g/km. Due to the higher BEV shares and the reduced number of highly equipped variants, the average contribution margin per vehicle decreases by 3% compared to the baseline scenario. However, the reduction in the excess emissions premium due to a lower deviation from the CO_2 target offsets for this effect. The average contribution margin after deduction of the excess emissions premium is even higher than in the baseline scenario (+7%).

Figure 6 Ecological and financial results of tactical sales planning as of March 1st for different objective functions



Notes: *M1 and N1 combined (volume weighted); **contribution margin; ***M1, N2, special purpose vehicles, and camper vans.

Similar to the first objective, following the CO_2 compliance derives a sales plan with maximum BEV and PHEV shares. However, to relax the regulatory requirements, the CO_2 target is increased by increasing the average weight of the fleet. This favours vehicles with a high weight to CO_2 ratio that do not substantially affect the average CO_2 value of the fleet. In addition, a shift in sales volumes from M1 to N1 registrations and to camper vans or special purpose vehicles allows for CO_2 compliance. Overall, this is associated with a reduced average contribution margin of –5.6% compared to the baseline scenario. Since no excess emissions premium applies, the contribution margin can be increased by 9.3%. By meeting the CO_2 target, manufacturers can also avoid reputational damage.

Increasing the average contribution margin leads to a sales plan characterised by a higher share of high-priced variants with many optional equipment items and often M1 registration. The sales volume of less profitable variants (including BEVs and PHEVs) and entry-level trim lines is reduced in favour of well-equipped ICEVs. Moreover, sales volumes are shifted to markets that demand more optional equipment on average. Compared to the baseline scenario, the average contribution margin increases by 6.9%. Due to an increase in CO_2 emissions (+7 g/km), the CO_2 target is exceeded by 14.6 g/km and the excess emissions premium inclines by 62% to €1,344 per vehicle. Therefore, the contribution margin decreases by –€97 after deducting the excess emissions premium.

The best financial result (+15% compared to the baseline) can be obtained in the case the manufacturer strives to maximise the contribution margin after deducing the excess emissions premium. The corresponding sales plan particularly consists of highly equipped vehicles with a very high weight (+11 kg). This results in a relaxed CO_2 target and an increase in the contribution margins simultaneously. In the sales plan, camper van registrations are favoured as they are not covered by the CO_2 regulation and offer high contribution margins. Plannable variants with little or no deviation from the CO_2 target and high to medium contribution margins are also advantageous. The remaining CO_2 deviation can be reduced by increasing the proportion of BEVs and PHEVs. From a financial perspective, this is beneficial if the reduction in excess emissions premiums is not overcompensated by declining contribution margins. The resulting sales plan exceeds the CO_2 target by only 2.7 g/km. Compared to the baseline scenario, a total reduction in CO_2 emissions by 5.7 g/km is achieved. Thus, both the financial and the environmental indicators can be improved.

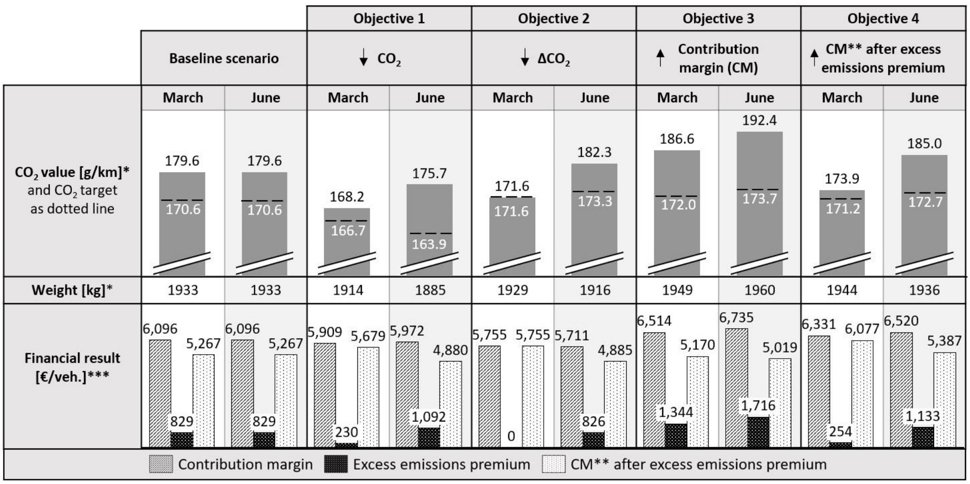
5.3 July tactical sales planning

To illustrate the importance of considering a rolling planning horizon, tactical sales planning is repeated in July. We assume that 70% of the total sales volume for the year has either already been shipped to customers or is in the frozen area of the planning horizon. Thus, tactical sales planning in July can only decide on 30% of the sales volume. In addition, three key planning assumptions are changed: firstly, the demand for PHEVs decreases by 25% due to the termination of government subsidies in a major market. Secondly, the global shortage of semiconductors reduces the flexibility to shift demand between variants (30% instead of 40%). Thirdly, the maximum production capacity for BEVs is reduced by 20% due to a shortage of battery cells. Furthermore, based on each market's average take rates on optional equipment within the first six months, a refinement of the characteristics of each plannable variant is undertaken, resulting in new figures for weights, CO_2 emissions, and contribution margins.

In Figure 7, the results of the July tactical sales planning are compared to the March results. With only 30% of the full year sales volume amendable, the possible degree of influencing the full year vehicle fleet and achieving a set objective is substantially reduced. Due to the lower sales potential for BEVs and PHEVs, the CO_2 fleet value (objective 1) increases by 4.5%. For similar reasons, it is not possible to meet the CO_2 target (objective 2). Instead, the target is exceeded by 9 g/km. The new constraints on the PHEV and BEV sales cause an increase in the contribution margin (objective 3) by €220, as demand is shifted to highly profitable ICEVs to keep total sales numbers constant. In turn, the contribution margin decreases by 11.4% after deducting the excess emissions premium (objective 4), which is substantially higher than for the March sales plan (€1,133 compared to €254 per vehicle).

In summary, two main effects of the rolling planning approach become apparent: Firstly, important information may change over time leading to new optimal sales plans. Secondly, the more vehicles are sold and frozen with each planning round, the lower is the flexibility to achieve a given objective in tactical sales planning.

Figure 7 Comparison between July and March tactical sales planning for different objective functions



Notes: *M1 and N1 combined (volume weighted); **contribution margin; ***M1, N2, special purpose vehicles and camper vans.

5.4 Recommendations for action

Based on the illustrative application, the following recommendations for tactical sales planning can be derived:

First of all, sales planning should pay particular attention to the objectives to be pursued. The application outlines that a focus on increasing average contribution margins does not necessarily lead to the best positive financial outcome as excess emissions premiums may increase at the same time. When seeking to improve the environmental performance, sales planning must take into account that reducing the CO_2 emissions and reducing the deviation from a fleet's individual CO_2 target are two completely different objectives. The results confirm that simultaneously reducing CO_2 fleet emissions and increasing contribution margins within tactical sales planning is indeed difficult but possible.

Secondly, for manufacturers seeking to meet the CO_2 target, our results indicate that the degree of freedom to comply with the European CO_2 legislation may in some cases lead to unintended effects. Shifting the sales volume of ICEVs to the registration types not covered by the EU legislation is one possible course of action. In addition, fulfilling the CO_2 targets can be met at least partially by systematically increasing the manufacturer-specific target due to higher average weights. However, such approaches would not be in line with the legislation's intention aiming at an overall reduction of the CO_2 emissions of the European vehicle fleet. We therefore propose that manufacturers of LCVs reduce the CO_2 emissions in all registration types beyond the achievement of the target, thus contributing continuously to the steady decarbonisation of the transport sector.

Thirdly, our study confirms that a rolling planning approach is suitable to cope with changing information about important constraints such as demand and production capacities. Over the course of a year, the ability to influence the composition of the vehicle fleet decreases with each planning execution. Therefore, companies should decide as early as possible on their objectives, analyse the feasibility of achieving the objectives on a regular basis, and take countermeasures immediately.

Finally, the complexity resulting from the large number of plannable variants for which the sales volume must be determined, suggests that sales planning requires an appropriate decision support for real-world scenarios. Sound decision making is essential to eventually improve the financial or environmental outcome of CO_2-oriented sales planning.

6 Conclusions

This article presents a framework for tactical sales planning of LCV manufacturers to manage the trade-off between reducing CO_2 fleet emissions and maximising contribution margins. The framework decides on the sales volumes of plannable variants at the level of different model groups, powertrain technologies, trimlines, registration types, and other relevant optional equipment items per sales market. Different ecological and financial objective functions as well as important constraints such as demand and production capacities are considered. The developed framework is especially relevant during the transition phase of the European LCV fleet from ICEV to zero emission technologies.

By applying the framework to an illustrative case study, we find that there are strong interdependencies between the objectives to be pursued, the resulting fleet composition, the achievement of CO_2 targets, and the contribution margins. Reducing CO_2 fleet emissions while maximising contribution margins at the same time will remain challenging until light-duty BEVs achieve both, substantial market shares and competitive contribution margins relative to ICEVs. In addition, a sufficient supply of battery cells and other components is a prerequisite for realising the full potential of BEVs in tactical sales planning. However, there are several other levers that can be used to influence the fleet composition and thus address the CO_2 management decision problem, in particular order acceptance and backlogging strategies. This influence diminishes over the course of the year as more vehicles are specified and delivered to customers.

The presented work has several limitations: Specific mechanisms of the EU CO_2 regulation such as eco innovations, super credits, and phase-in are not considered, but may have an additional impact on the achievement of CO_2 targets. In addition, our framework only considers one specific planning year whereas in practice, sales backlogging decisions also affect the succeeding planning period. While the framework and the heuristic to derive sales plans works well for our relatively small scenario, the applicability to industry-relevant problem sizes is limited. Moreover, the restrictions arising from production and supply capacities reflected in our case study are simplified. In a real-world planning situation, production and supply capacities must be handled individually for each item and component. Moreover, several parts can be used to build a wide range of vehicle models. Thus, interdependencies must be regarded. As we have focussed on the perspective of sales planning, future research will emphasise these production-oriented restrictions.

Succeeding work will concentrate on transferring the presented framework into an optimisation model to derive mathematically optimal sales plans for industry-relevant problem sizes. In addition, two consecutive planning years shall be implemented to model consequences of sales backlogging strategies beyond December 31st of the current planning period.

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Notes

1 Since 2022 also average CO_2 and vehicle weights from prior years are relevant for the exact CO_2 fleet target calculation.

2 In 2021, BEVs accounted for less than 3% and (plug-in) hybrids for 1.7% of new registered LCVs in Europe (ACEA, 2022b).

3 Further details of the legislation such as the effect of 'eco-innovations', 'super credits' or 'phase-in' rules are not considered for this article.

4 The standard for measuring and calculating a vehicle's CO_2 emissions has changed from NEDC to WLTP. As these standards give very different results, the CO_2 fleet target is influenced by a certain factor in the formula to allow for comparability.

Appendix

Table A1 Scenario specific illustrative data (excerpt for the A segment only, all values are fictive)

Segment	*Model*	*Technology*	*Trimline, packages*	*Engine*	*Transmission*	*Registration*	*Sales market*	*Weight*	CO_2	*CM*
A	City window van	BEV	EWV-1	110 kW 60 kWh	1-gear RWD	M1	A	2,290.80	0	6,720.45
	City window van	BEV	EWV-2	110 kW 60 kWh	1-gear RWD	M1	B	2,287.88	0	5,339.90
	City window van	BEV	EWV-3	110 kW 60 kWh	1-gear RWD	M1	C	2,277.25	0	4,259.85
	City window van	ICE	ICWV-10	75 kW 2 L diesel	7-gear FWD	M1	C	1,586.24	128.39	2,264.49
	City window van	ICE	ICWV-11	110 kW 2 L diesel	7-gear 4WD	M1	B	1,559.52	151.21	3,341.30
	City window van	ICE	ICWV-3	110 kW 2 L diesel	7-gear FWD	M1	A	1,435.30	143.06	3,995.68
	City window van	ICE	ICWV-4	110 kW 2 L diesel	6-gear FWD	M1	A	1,497.96	124.56	2,182.94
	City window van	ICE	ICWV-5	110 kW 2 L diesel	6-gear FWD	M1	B	1,464.59	142.92	2,171.47
	City window van	ICE	ICWV-7	65 kW 2 L petrol	7-gear FWD	M1	B	1,600.73	136.21	5,615.83
	City window van	ICE	ICWV-8	65 kW 2 L petrol	7-gear FWD	M1	C	1,577.05	129.39	3,164.37
	City window van	ICE	ICWV-9	110 kW 2 L diesel	7-gear FWD	M1	A	1,539.40	151.95	5,022.72
	City panel van	BEV	ECPV-1	100 kW 60 kWh	1-gear RWD	N1	C	2,188.63	0	3,001.50
	City panel van	BEV	ECPV-1	100 kW 60 kWh	1-gear RWD	N1	B	2,178.35	0	2,699.88
	City panel van	BEV	ECPV-1	100 kW 60 kWh	1-gear RWD	N1	A	2,188.28	0	2,759.95
	City panel van	ICE	ICPV-1	75 kW 2 L diesel	6-gear FWD	N1	C	1,398.83	124.39	1,265.32
	City panel van	ICE	ICPV-1	75 kW 2 L diesel	6-gear FWD	N1	A	1,398.95	124.56	2,295.33
	City panel van	ICE	ICPV-1	75 kW 2 L diesel	6-gear FWD	N1	B	1,400.32	125.29	2,046.46
	City panel van	ICE	ICPV-2	65 kW 2 L petrol	6-gear FWD	N1	C	1,398.20	124.73	2,336.95
	City panel van	ICE	ICPV-2	65 kW 2 L petrol	6-gear FWD	N1	A	1,501.87	137.90	3,567.45
	City panel van	ICE	ICPV-2	110 kW 2 L diesel	6-gear FWD	N1	A	1,553.69	140.13	4,250.95
	City panel van	ICE	ICPV-2	110 kW 2 L diesel	6-gear FWD	N1	B	1,561.43	140.79	4,748.65
	City panel van	ICE	ICPV-5	110 kW 2 L diesel	7-gear 4WD	N1	A	1,388.68	143.83	2,688.57
	…	…	…	…	…	…	…	…	…	…