IMPACT OF NOISE MITIGATION SOLUTIONS FOR L-VEHICLES

Michael Dittrich[1], Heinrich (Heinz) Steven[2]

[1]Department of Acoustic Signatures and Noise Control, TNO, The Hague, The Netherlands
[2]HS Data Analysis and Consultancy, Heinsberg, Germany

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Abstract

In the EU project LENS, potential noise mitigation solutions for noise from L-vehicles were proposed. L-vehicles include motorcycles, mopeds, trikes, quads/ATVs and microcars. An impact analysis and cost-benefit analysis was made based on average L_{den} sound levels and on single events. Single events are the main cause of annoyance and complaints. In this paper, both methods are presented and the cost-effectiveness is ranked for the mitigation scenarios. These include improved type testing methods, reduced tampering, improved driving behaviour, access restrictions and fleet replacement. The results are indicative but suffice to rank the scenarios, showing that reduced vehicle tampering is highly effective, followed by access restrictions and improved driving behaviour.

Keywords: *Vehicle noise, motorcycles, mopeds, mitigation, impact analysis*

1. Introduction

In the EU project LENS [1], potential noise mitigation solutions for noise from L-vehicles were proposed. L-vehicles include motorcycles, mopeds, trikes, quads/ATVs and microcars.

The mitigation solutions proposed in LENS are aimed at the fleet and at road infrastructure and are defined in scenarios relative to a baseline situation in 2025 [2]. These are ranked in terms of impact and benefit-to-cost ratio. An impact analysis and cost-benefit analysis was made based both on average L_{den} sound levels and on single events. Single events from loud vehicles are a major source of disturbance and are not so well reflected in average quantities such as L_{den}. The L_{den} level is a long term average equivalent sound level with a weighting for the day, evening and night periods.

Corresponding author: *michael.dittrich@tno.nl.*

This paper describes the mitigation scenarios together with the methods for impact analysis and cost-benefit analysis at EU level, the assumed inputs and the findings. It is based on work done in the LENS project reported in [2] where more background data can be found.

2. Mitigation scenarios

2.1 Baseline

The baseline situation is defined for 2025 as set out in [2], including key parameters such as the fleet composition, vehicle sound emission, vehicle tampering rates, road lengths, traffic flow rates, exposed population, and current EU, UNECE and national/local regulations.

The projection period for the scenario analysis is 2025–2050, focused on the EU27. In recent years the motorcycle fleet has grown and is expected to continue to do so, whereas the moped fleet is decreasing. In 2050, an electrification rate for all L-vehicles is estimated between 17% (low) and 50% (high).

2.2 Scenario M1: Improved type testing regulation

Potential improvements to the UNECE regulations for noise type approval of L-vehicles include:

- Cover the full engine speed range and vehicle speed range, including loudest conditions.
- Limit very high sound levels (>90 dB(A)) allowed in current regulation.
- Stricter sound limits for acceleration noise (L_{WOT}).

The expected effect is mainly for new vehicles, of around 2–5 dB in single events, depending on its implementation. It may be more for specific loud driving conditions such for high engine speed and high load conditions. Given that this will only affect new vehicles, it will take longer than the average vehicle lifetime to take effect for the whole fleet. Subscenario M1a assumes 1.5 dB reduction in real traffic, subscenario M1b assumes a more demanding 3 dB reduction in real traffic.

2.2 Scenario M2: Reduced vehicle tampering and modifications

Vehicle modifications which increase power and/or noise can be outside the type approval specifications and thereby no longer road legal. Common tampering methods are silencer replacements, removed dB-killers, speed derestriction, engine tuning and many others. Based on investigations, fleet tampering rates were estimated in LENS at 45% for mopeds and 15% for motorcycles. In order to reduce this, solutions are envisaged such as improved inspection and roadside checks, improved periodic inspection and automated monitoring systems and tools to simplify enforcement. Periodic inspection for motorcycles including noise should be mandatory for those countries not yet requiring it. Tampered vehicles often also display loud driving behaviour. Subscenario M2a is for 100% reduction of tampered vehicles, M2b is for 67% reduction.

2.3 Scenario M3: Local regulations to improve driving behaviour

Driving behaviour particularly affects noise emission, especially for high engine speeds and high acceleration. This can be in part controlled by lower speed limits, road design and enforcement against loud driving, either by enforcement officers or by fixed or mobile noise cameras. Speed limits can reduce acceleration levels and thereby noise, besides improving road safety. Significant variation in driving behaviour for a given traffic situation requires a high excess power output. This is most relevant for medium to large motorcycles above 250 cc (or category L3e-A2/A3), whereas tampering occurs for all L-vehicles. The results from the LENS project confirm this [3],[6]. This scenario assumes 100% reduction of high rev driving.

2.4 Scenario M4: Local access restrictions

Local access restrictions for L-vehicles can be a highly effective measure to reduce the noise impact. It can include time or vehicle specific restrictions including quiet zones, for example allowing only electric vehicles or excluding vehicles previously identified as too loud. Subscenario M4a is only for motorcycles above 250 cc, M2b is for all L-vehicles.

2.5 Scenario M5: Accelerated vehicle replacement

Quieter vehicles, in particular electric, can be subsidised to replace the old noisier fleet at a higher rate. Given the current electrification levels, it is expected that this would take many years at relatively high cost to the taxpayer. A low subscenario M5a for 17% electrification and a high subscenario M5b for 50% are defined for 2050.

In summary, scenarios 2, 3 and 4 can be implemented and take effect in the short term, whereas scenarios 1 and 5 take many more years to take effect.

2.6 Other options

Besides the above scenarios the following was also recommended, although not included in the impact analysis:

- Improving driver awareness, such as interactive signing, information and training, to encourage quieter driving;
- Revision of the sound source levels for L-vehicles in the EU traffic noise calculation method CNOSSOS (Directives 2015/996 and 2021/1226);
- Improved market surveillance for replacement and add-on parts.

3. Impact on L_{den} levels

The impact of each scenario has been estimated for different road types in the EU, with their speed limits, total lengths, driving characteristics (free flowing or intermittent), typical traffic flow rates and population densities along roads. The impact is calculated in terms of the change in L_{den} levels along each road type for each scenario, further subdivided into two EU regions (North and South) with significantly different L-vehicle shares. The ROTRANOMO/TRANECAM models [7] were used for this. Also, the growth of the fleet, change in sound levels due to UN regulations and rate of electrification were taken into account.

The road categories, traffic load and vehicle category shares and the differentiation of two EU regions that were applied to the L_{den} calculation scenarios are based on the approach that was used in the "Study on Euro 5 sound level limits of L-category vehicles" [4]. The change in L_{den} level was also converted to a monetised value for benefits, using a valuation method.

The evolution of L_{den} reductions near the road for some selected scenarios are set out in Tables 1, 2 and 3, which also show the road types and speed limits. More variants for the scenarios and their details are provided in the LENS report D6.4 [2].

Table 1. Results of the L_{den} calculations for scenario M2a (tampered vehicles reduced completely), no future Euro 6 L-vehicles, low electrification scenario, Northern EU.

Road category, scenario, electrification scenario and region	Delta Lden in dB(A) compared to baseline scenario					
	2025	2030	2035	2040	2045	2050
Urban / Access-residential / SpLimit:30	-0.56	-0.65	-0.70	-0.71	-0.69	-0.65
Urban / Distributor-District Connection / SpLimit:50	-0.38	-0.44	-0.48	-0.48	-0.46	-0.44
Urban / Main (Trunk Road) / SpLimit:70	-0.27	-0.30	-0.32	-0.32	-0.31	-0.30
Urban / City-Motorway / SpLimit:100	-0.12	-0.21	-0.22	-0.22	-0.22	-0.21
Rural / Trunk Road / SpLimit:90	-0.33	-0.38	-0.40	-0.40	-0.39	-0.37
Rural / Motorway / SpLimit:120	-0.12	-0.21	-0.22	-0.22	-0.22	-0.21

Table 2. Results of the L_{den} calculations for scenario M2a (tampered vehicles reduced completely), no future Euro 6 L-cat, low electrification scenario, Southern EU.

Road category, scenario, electrification scenario and region	Delta Lden in dB(A) compared to baseline scenario					
	2025	2030	2035	2040	2045	2050
Urban / Access-residential / SpLimit:30	-1.39	-1.98	-2.05	-2.03	-1.94	-1.80
Urban / Distributor-District Connection / SpLimit:50	-1.01	-1.24	-1.29	-1.28	-1.21	-1.12
Urban / Main (Trunk Road) / SpLimit:70	-0.79	-0.94	-0.98	-0.96	-0.91	-0.84
Urban / City-Motorway / SpLimit:100	-0.32	-0.43	-0.45	-0.46	-0.45	-0.44
Rural / Trunk Road / SpLimit:90	-0.85	-0.91	-0.96	-0.95	-0.90	-0.85
Rural / Motorway / SpLimit:120	-0.31	-0.42	-0.45	-0.45	-0.44	-0.43

Table 3. Results of the L_{den} calculations for scenario combination M1b (with future Euro 6 L-cat -3 dB from 2028 on), M2b (2/3 of tampered vehicles replaced by legal ones), M3 (no aggressive driving behaviour) and M4a (access restrictions for motorcycles above 250 cc) and conservative electrification scenario, for Northern and Southern EU separately.

Road category, scenario, electrification scenario and region	Delta L_{den} in dB(A) compared to base scenario					
	2025	2030	2035	2040	2045	2050
Urban / Access-residential / SpLimit:30, Northern EU	-1.30	-1.48	-1.70	-1.81	-1.81	-1.75
Urban / Distributor-District Connection / SpLimit:50, Northern EU	-0.93	-1.05	-1.21	-1.27	-1.26	-1.22
Urban / Main (Trunk Road) / SpLimit:70, Northern EU	-0.57	-0.65	-0.74	-0.77	-0.76	-0.73
Rural / Trunk Road / SpLimit:90, Northern EU	-0.60	-0.70	-0.85	-0.92	-0.91	-0.88
Urban / Access-residential / SpLimit:30, Southern EU	-3.03	-3.43	-4.00	-4.29	-4.32	-4.23
Urban / Distributor-District Connection / SpLimit:50, Southern EU	-2.36	-2.65	-3.06	-3.26	-3.25	-3.16
Urban / Main (Trunk Road) / SpLimit:70, Southern EU	-1.61	-1.82	-2.10	-2.22	-2.19	-2.11
Rural / Trunk Road / SpLimit:90, Southern EU	-1.53	-1.77	-2.17	-2.37	-2.37	-2.31

The analysis of the results of the L_{den} calculation can be summarised as follows:

- Since the L-vehicle shares for the Southern EU region are significantly higher than for the Northern EU region (almost 3 times for motorcycles and almost 5 times for Mopeds) this resulted in L_{den} reductions that are just over twice as high for the Southern EU region compared to the Northern EU region.
- The differences in L_{den} reduction between the two electrification scenarios are not significant but show a tendency towards slightly lower values for the optimistic electrification scenario.
- According to road categories the rank order of the L_{den} reduction for a given measure in descending order is as follows:
  - Residential streets with speed limit of 30 km/h
  - Urban main streets with speed limit of 50 km/h
  - Rural roads with speed limit of 90 km/h / urban main streets with speed limit of 70 km/h
  - Motorways.
- The rank order of the reduction measures/scenarios is in descending order of efficiency:
  - M4b access restrictions for all L-cat vehicles (not applied on motorways),
  - The combination M1b, M2b, M3 and M4a (introduction of Euro 6 L-cat vehicles from 2028 on with 3 dB(A) lower noise emissions in real traffic, complete elimination of tampered vehicles and high rev driving behaviour, access restrictions for motorcycles >250 cm³), also not applied on motorways,
  - M4a access restrictions for motorcycles >250 cm³,
  - M2b complete elimination of tampered vehicles.

The scenarios M1, M3 and M5b are less effective (L_{den} reduction for the southern EU region below 0.5 dB(A)).

4. Impact on single events

Also the impact of single events from L-vehicles can be estimated, using the method described below. It was initially developed for the L-vehicle sound limits study in 2017 [4]. The same types of roads are used as for the L_{den} analysis, but the effects of other traffic are not included, only the peak noise sound levels of L-vehicles. No distinction was made between Northern and Southern EU areas.

An estimate is made of the number of loud events per year per km road, based on activity rates per vehicle and road type, fraction of road length where this may occur (as listed in [2]). Typically, this is at road sections with dynamic driving such as acceleration or deceleration, set at 33%. 50% of these are included where single loud events may occur, and only road sections with dwellings along them. This amounted to 437239 km of roads in the EU27 where loud events could occur, out of 4.6 million km in total. 26.5 million motorcycles were assumed for the EU27, with average mileage of 5100 km/year.

A loud event is defined as any sound level above the average L_{WOT} sound level from type approval. This is typically above 80 dB(A) at the roadside and stands out clearly compared to most cars and even heavy vehicles such as buses and trucks. The impact is in terms of the average reduction in these events based on changed vehicle sound emission levels, driving behaviour or vehicle modifications. These reductions are larger than those in the L_{den} levels (see Tables 4, 5 and formula (4)).

Number of single events

The number of single events can be estimated at vehicle level, in relation to the annual mileage. If the number of people or dwellings along the road per km is known, then a total number of single events at dwellings can be estimated, taking into account only inhabited roads with dynamic/intermittent traffic (33%) and half of those (50%) where single loud events may occur.

The number of kilometres per vehicle per year per road type during which single events occur $N_{km,veh,r,y}$, is based on total annual vehicle mileage d_y, activity rate per road type a_r and portion of road affected p_r of the total road length:

$$N_{km,veh,r,y} = d_y \times a_r \times p_r \qquad (1)$$

The total number of single events per year $N_{tot,r,y}$ for all households per road type is obtained from $N_{km,veh,r,y}$, active fleet size N_{veh}, the number of households per km $N_{hh,km,r}$ and the portion of each km where an event occurs, $f_{km,r}$:

$$N_{tot,r,y} = N_{km,veh,r,y} \times N_{veh} \times N_{hh,km} \times f_{km,r} \qquad (2)$$

The total number of single events per year $N_{tot,y}$ for all affected households is the sum over all road types:

$$N_{tot,y} = \Sigma\, N_{tot,r,y} \qquad (3)$$

For each single event, an effective maximum sound level L_{pAmax} at 7.5 m distance is defined as

$$L_{pAmax} = L_{WOT} + \Delta L_{lim} + \Delta L_{drive} + \Delta L_{mod} \qquad (4)$$

where

L_{WOT} = wide open throttle sound level as defined by the type approval limit

ΔL_{lim} = correction due to changed sound limit;

ΔL_{drive} = correction for driving conditions including the ASEP range, also engine revving, acceleration from standstill and acceleration at higher speeds;

ΔL_{mod} = correction taking tampering and vehicle modifications (all types) into account.

An average L_{pAFmax} for L-vehicles, based on average type approval level $L_{TA,avg}$, adjusted for tampering, engine speed, acceleration (loading) and off-cycle driving condition, is calculated from

$$L_{\mathrm{AFmax,avg}} = L_{TA,avg} + \sum (p_i \times \Delta L_i) \qquad (5)$$

with a level difference ΔL_i as in formula (4) and percentage p_i of vehicles (fleet fraction) for each of the above factors. Then the effect of changes due to a scenario compared to the baseline is derived from

$$\Delta L_{\mathrm{AFmax,avg}} = L_{\mathrm{AFmax,avg,ref}} - L_{\mathrm{AFmax,avg,scen}} \qquad (6)$$

The assumed reductions for each scenario are set out in Table 4 and Table 5. For local regulations and access restrictions a lower portion of roads is selected of 20% and 10% respectively, as these are not applicable everywhere. Access restrictions (M4) and vehicle replacement (M5) are assigned a nominal reduction of 10 dB. Reduced tampering (M2) and improved driving behaviour (M3) are assigned an effective reduction of 5 dB, which is weighted for the portion of the fleet affected. Improved type approval legislation is assigned 2 dB reduction as it only affects new vehicles and will be limited in reduction potential.

Table 4. Road parts affected, effectuation time in real traffic and average reduction in single event sound levels for each scenario.

Scenario	Percentage of roads affected	Effectuation time in years	ΔL_{pAFmax} dB
M1	100%	25	2
M2	100%	10	3.33
M3	20%	10	3.33
M4	10%	15	10
M5	100%	15	10

Table 5. Assumed reductions in average single events relative to the reference situation, considering mitigation of driving behaviour and tampering/modifications.

Scenario and fleet portion		Level excess	Avg. level excess	Average single event reduction
Reference situation (2025)		dB	dB	dB
10%	Modified vehicle	5	6.7	
10%	Driving behaviour	5		
10%	Both	10		
70%	Normal	0		
A.Driving behaviour				
10%	Modified vehicle	5	3.3	3.3
10%	Driving behaviour	0		
10%	Both	5		
70%	Normal	0		
B.Modified vehicles				
10%	Modified vehicle	0	3.3	3.3
10%	Driving behaviour	5		
10%	Both	5		
70%	Normal	0		
C.Both				
10%	Modified vehicle	0	0.0	6.7
10%	Driving behaviour	0		
10%	Both	0		
70%	Normal	0		

5. Benefits and costs

Benefits are defined in terms valuation for amenity and health and are expressed here as a monetized value for both combined. Valuation figures are taken from the L-cat sound limits study [4] , corrected for inflation to 2025. These amount to 20,73 Euro per dB/person/year (or 49,75 Euro per household per year assuming an average of 2,4 persons per household). This is a fairly conservative figure compared to others. For long term sound exposure in terms of L_{den} and L_{night}, so-called dose-effect relationships are given in EU Directive 2020/367 for ischemic heart disease (IHD), high annoyance (HA) and high sleep disturbance (HSD), which allows the calculation of numbers of statistically affected people for road traffic. These increase exponentially for increasing L_{den} and L_{night} levels. They are not used here, to avoid assessing the absolute L_{den} levels for each dwelling situation. Calculated annual benefits for each scenario over the period 2025-2050 for the EU27 are set out in Fig.1 for L_{den} reductions and single event reductions. These include 1% interest rate and 4% discount rate.

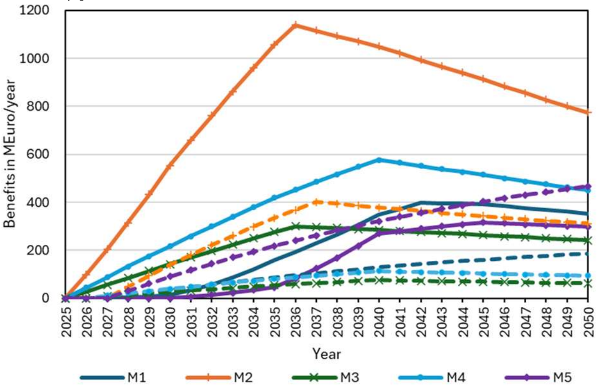

Figure 1. Annual benefits for each scenario, for L_{den} reductions, and dashed lines, for single event reductions.

The slope discontinuities are due to the evolution of the sound reductions, i.e. these reach full effect after a number of years. The lower benefits for single events are due to the lower valuation used and the lower effective road lengths.

For single events of L-vehicles, no standard valuation data or dose-effect relationships are known. Studies have shown that for L-vehicles, the annoyance levels are much higher than for other vehicles [8],[9], and sound levels can be significantly higher than for other vehicles, which is both evident for roadside measurements [5] and from type approval levels (L_{WOT} including ASEP). Therefore, an alternative approach is required to assess impacts of single events, as also introduced in the L-cat sound limits study [4]. A proposed valuation index is used to assess benefits of reduction of single event sound levels of 0,001 Euro (one tenth of a cent) per dB reduction per household per event. This is assumed to include all the above effects and is a very conservative amount compared to noise valuation for L_{den}. For example, 1000 single events at one household in a year with an excess sound level of 10 dB above average cars, would amount to 10x1000x0,001 = 10 Euros, or 10/2,4 = 4,17 Euros per person per year.

For each scenario, benefits are calculated for each year, based on the change in L_{den} levels or average L_{pAFmax} levels. These are multiplied by the noise valuation and the number of people exposed for each road type. The numbers of people exposed in turn depend on road lengths with exposed people and population density along these roads.

Costs are defined as additional costs for each affected stakeholder group due to each scenario. These are used for both the L_{den} and the single event analyses. Costs are generally harder to estimate due to lack of information but can be 'boxed in' by taking relevant factors into account. For industry, additional R&D and manufacturing costs are foreseen. For public authorities, additional costs are foreseen for roadside enforcement, vehicle inspection, road infrastructure and vehicle subsidies. Further details on the cost estimations are given in [2] Appendix C. The distributions for each scenario are shown in Table 6 for each stakeholder. The effectuation time is shorter than in Table 4, as it refers to time to implement measures.

Table 6. Accumulated costs in 2050 for each scenario and stakeholder.

Scenario	Effectuation time, years	R&D (Industry)	Manufacturing (Industry)	Enforcement staff and equipment	Vehicle inspection and handling	State subsidies	Infra structure	Total
		MEuro	MEuro	MEuro	MEuro	MEuro	MEuro	MEuro
M1	5	9	518					527
M2	5			270	406			676
M3	10			270			128	398
M4	10			270			128	398
M5	10					4178		4178

In general, an overall annual cost estimate is made for each cost type, which is then weighted over time, depending on how it evolves. This is shown in Fig.2. In the same way as for benefits, 1% interest rate and 4% discount rate were applied. The benefit-to-cost ratio is calculated from the benefits and costs accumulated over the time period up to 2050. This is shown in Fig.3 both derived for the L_{den} and for the single event analysis. The accumulated values over the whole period are listed in Table 7.

6. Conclusions

Both the L_{den} analysis and single event analysis show the highest benefit-to-cost ratio for scenario M2 (reduced tampering) followed by M4 (Access restrictions) and M3 (Driving behaviour). Combinations also score relatively high. Scenarios M1 and M5 score relatively low due to high costs and long implementation time, except M1 for single events.

The reductions in single event levels are larger than those in the L_{den} levels. Based on the L_{den} analysis, the highest impact for the scenarios can be achieved at residential roads, main roads, arterial and rural roads. The effects are higher in the Southern EU than the

North, due to a higher proportion of L-vehicles in the South.

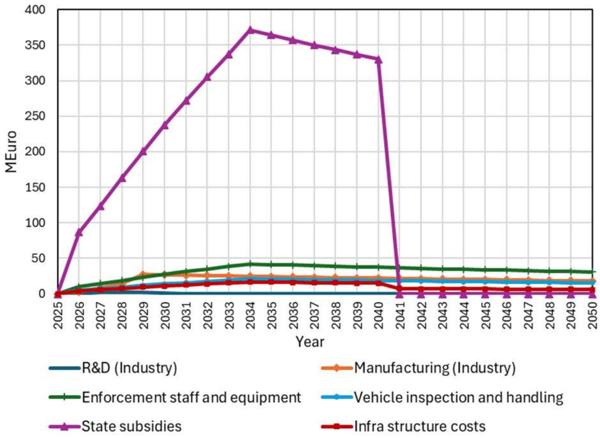

Figure 2. Accumulated costs per stakeholder up to 2050.

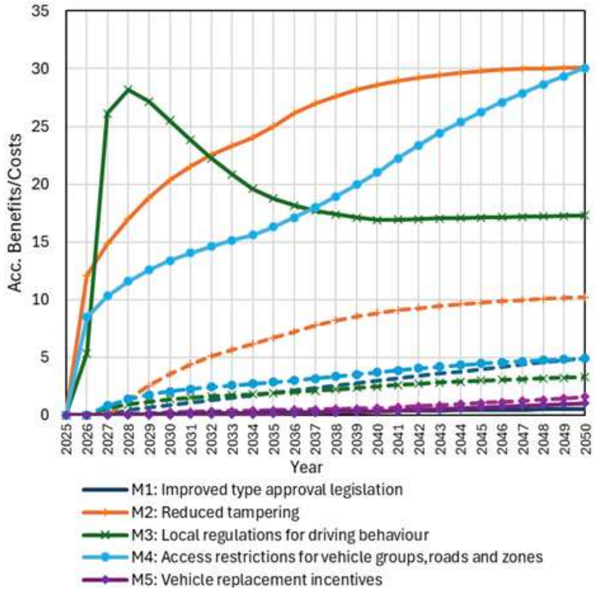

Figure 3. Benefit-to-cost ratio evolution up to 2050, for L_{den} (solid lines) and single event (dashed lines) analysis.

Table 7. Accumulated benefits and costs and benefit-to-cost ratio in 2050 for each scenario.

	CBA based on Lden			**CBA based on single events**		
	Acc. benefits	Acc. costs	B/C	Acc. benefits	Acc. costs	B/C
Scenario	MEuro	MEuro		MEuro	MEuro	
M1	263	527	0.50	2600	527	4.9
M2	20335	676	30.1	6902	676	10.2
M3	6884	398	17.3	1299	398	3.3
M4	11969	398	30.1	1949	398	4.9
M5	4198	4178	1.00	6501	4178	1.6
M1+M2+M3+ M4	39451	2000	19.7	12751	2000	6.3
M1+M2+M3+ M4+M5	43648	6178	7.1	19251	6178	3.1

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