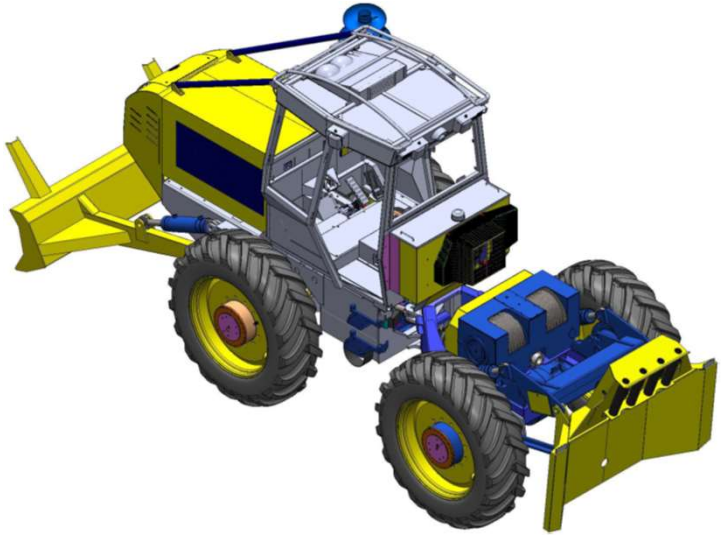
The development of electric hybrid drive of forest tractor – skidder



Prof. dr. sc. Marijan Šušnjar

Doc. dr. sc. Zdravko Pandur

Assoc. Prof. Hrvoje Nevečerel

Doc. dr. sc. Kruno Lepoglavec

Juraj Karlušić, mag. ing. mech.

Hrvoje Kopseak, mag. ing. silv.

Research was co-funded by the European Regional Development Fund, in the scope of the European Union Operational Programme «Competitivness and Cohesion» under the grant KK.01.1.1.04.0010 (**Development of hybrid drive of skidder—HiSkid**).

in partnership between the Faculty of Forestry and Wood Technology and the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb.

MAIN ISSUES

The use of forest machines in timber harvesting needs to fulfill following criteria:

Economic - fulfilling demands for the greater productivity with decreasing operational costs.

Ecological - decreasing damages of the forest ecosystem (soil treading and compaction, erosion processes, damages to trees and root system, pollution or contamination of air, soil, water resources, etc.)

Ergonomic - fulfilling demands for the better protection of health of the operator, avoiding risk of injury

Energy – decreasing consumption of fuels, avoiding wheel slip

MAIN ISSUES

Growing demand for forest machines that cost less to operate, along with regulatory pressures for lower emissions, increase manufacturers' interest in developing electric and hybrid drives compared to traditional hydraulic and mechanical ones.

Pure electric drives of forest machines meet a lot of bottlenecks:

- costs and reliability of the electric components,
- battery durability,
- charging (where, when and how long)
- size of batteries which could ensure enough energy for 8 h working time.

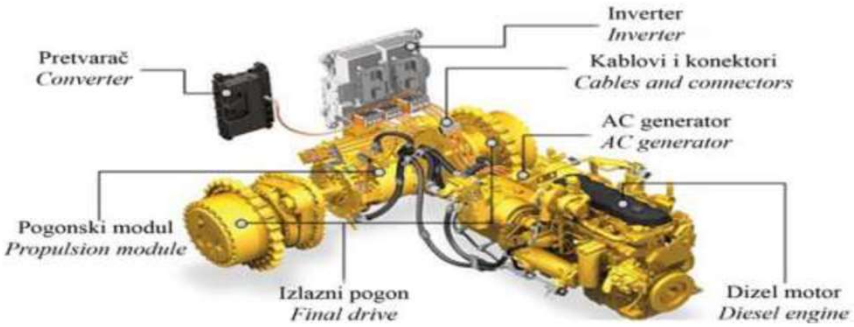
Hybrid solutions were seen as alternative for pure electric vehicle solution.

Forest vehicles offer big possibilities for the use of hybrids.

MAIN ISSUES

Common drivers of development of hybrid drive solutions in forest vehicles are:

- low emissions and noise,
- high performance,
- fuel efficiency,
- regulation (Emission standards for non-road diesel engines)
- public image.



Hybrid drives offer a favorable solution for the propulsion of forestry machinery in terms of:

➢ Possibilities of using a lower power diesel engine (lower fuel consumption)

➢➢ Possibility of hybrid drive operation with better mechanical performance compared to conventional drive system

SKIDDER

- Self-propelled, articulated forest vehicle for skidding trees or parts of trees

SKIDDER WITH A WINCH

- The most used machine in the countries of Central and Southern Europe
- Used in hilly and mountainous areas
- Approximately 500 skidders in Croatian forestry
- Approximately 55% of the total timber assortments are extracted by skidders using a winch

SKIDDER – work cycle

- unloaded travel from the roadside landing to the felling area in the forest,
- the operation of the winch (pulling out of winch rope and winching of the load),
- travel of the loaded skidder to the roadside landing area
- unloading

Skidder is stationary during winching time and diesel engine is running only for propuslion of hydraulic powered winch.

The share of forest winch work in the total working time:

Hilly terrain - from 21.8% to 36.0% of the total effective time

Mountain terrain - up to 48% of the total effective time

RESEARCH AIM

Skidder, so far, has not been considered a forest vehicle with hybrid drive capabilities.

A prerequisite for the development of a hybrid drive is the precise determination of the energy consumption of the skidder at different operating tasks and under different field conditions.

For this purpose, it is necessary to perform field measurements on existing vehicles, then conduct an adequate analysis of the collected data which, after processing, are used as a basis for the development of hybrid drives.

SKIDDER TYPE

- Ecotrac 140 V, manufactured by Hittner d.o.o

Engine	Cummins Inc; QSB4.5
Engine cooling	Water cooling
Number of cylinders	4 in-line cylinders
Working volume	4500 cm^3
Rated power	104 kW at 2000 min^{-1}
Torque	622 Nm at 1500 min^{-1}
Exhaust gas standards	EPA/COM IIIB Tier 4(I)
Weight	8060 kg
Winch	2 – drums; 2 × 100 kN

Research area

- Lika – Senj County – timber skidding from selective fellings on mountainous terrains

MEASUREMENTS

Differential fuel flow meters– DFM 100 D

Model	Minimum flow rate in each measuring camera, L/h	Maximum flow rate in each measuring camera, L/h	Measurement inaccuracy, ± %
DFM 100D	10	100	3

Nominal / Max fuel pressure, MPa	0,2 / 2,5
Min / Max kinematic viscosity, mm^2/s	1,5 / 6.0
Infiltrations size in the liquid, mm	0,08
Min / Max supply voltage, V	10 / 45
Max current consumption, mA, dor Unom = 12/24 V	50 / 25
Operating temperature, °C	-40 … +85 / -20 … +60
Ingress protection rating (IP Code)	54

Measurement precision = 0,001 L

MEASUREMENTS

Mobilisis – measuring equipment (installation)

WIGO-E (Telematic Data collector) gateway

- collecting and storing data from sensors and motor computer via CANBUS
- integrated GPS system
- data transfer of WLAN, LAN and GSM communication to Web platforms (Cloud).

MEASUREMENTS

Remote measurements

- Fuel consumption (mL)
- position (travelling route) of skidder (lat, lon)
- Detection of winch work (0, 1)
- Engine rpm (min^{-1})
- Engine torgue (% od max)
- Throttle position (%)

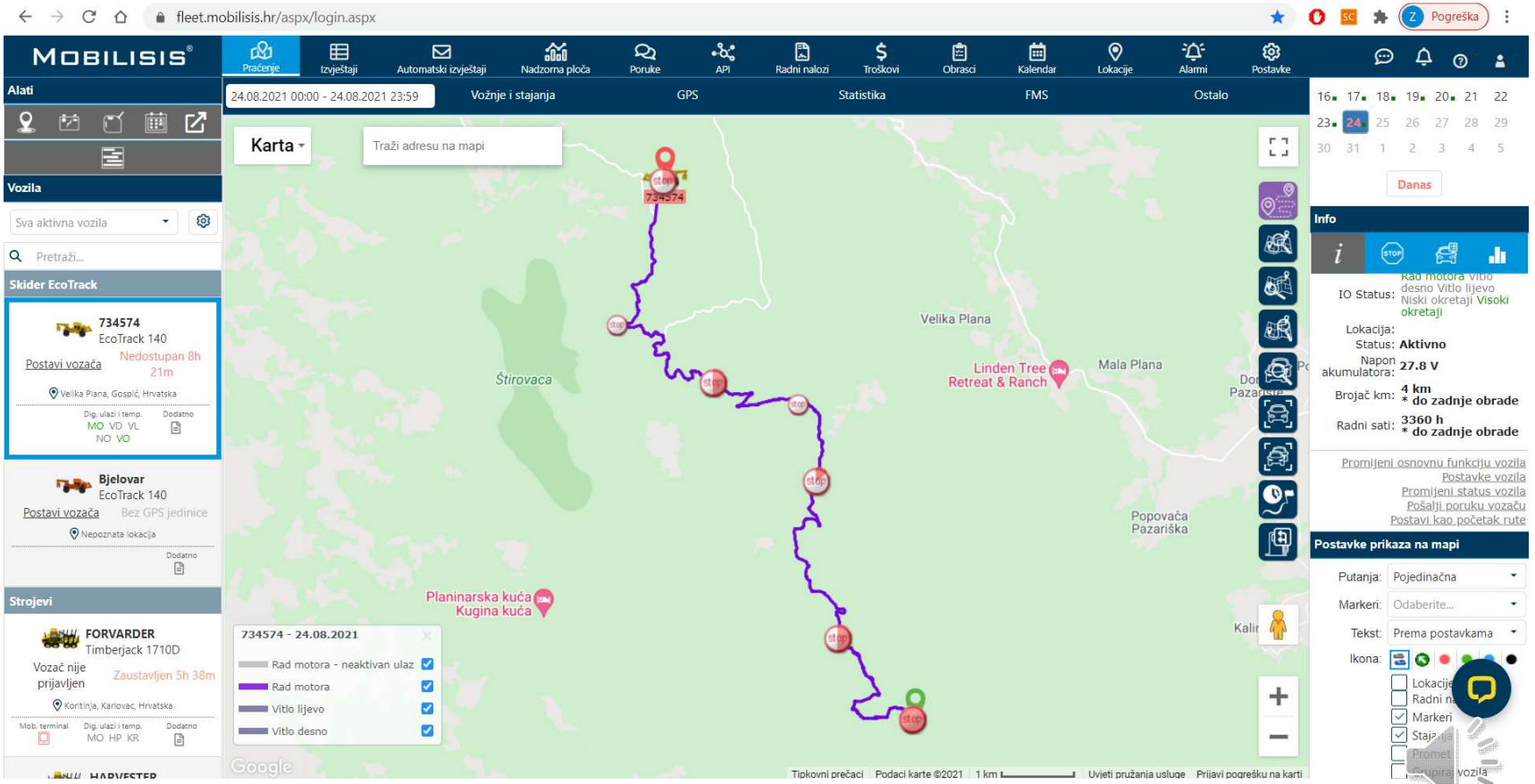
- sampling frequency – 3-5 s

Terrain measurements

- skidder load volumes per cycles
- slopes of skid trails (GNSS)

DATA COLLECTION

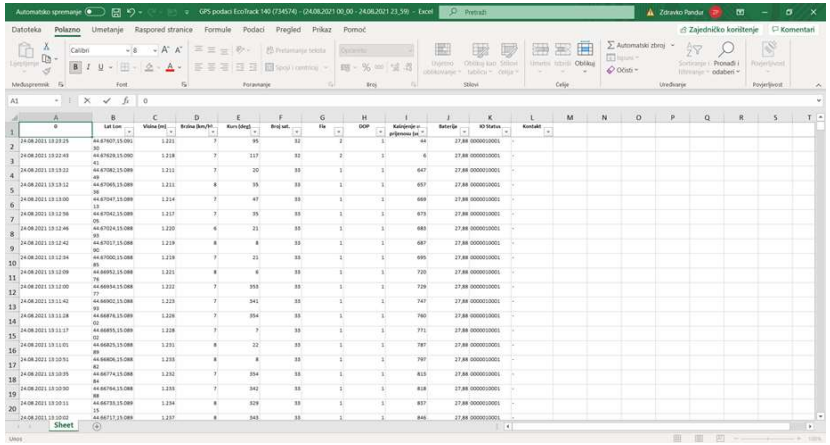
- Web platform
- Mobilisis interface
- Vehicle operation reports (graphic and tabular display, .xlsx, .pdf)

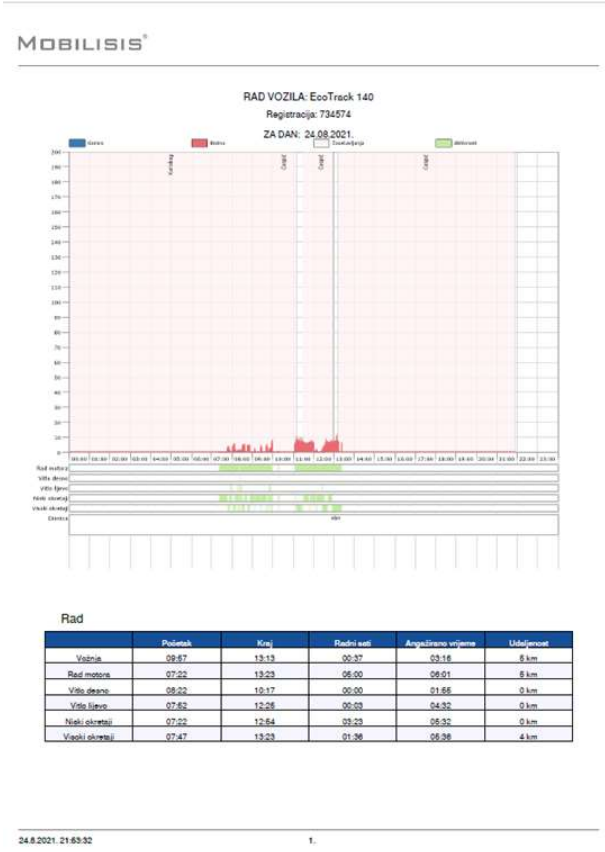


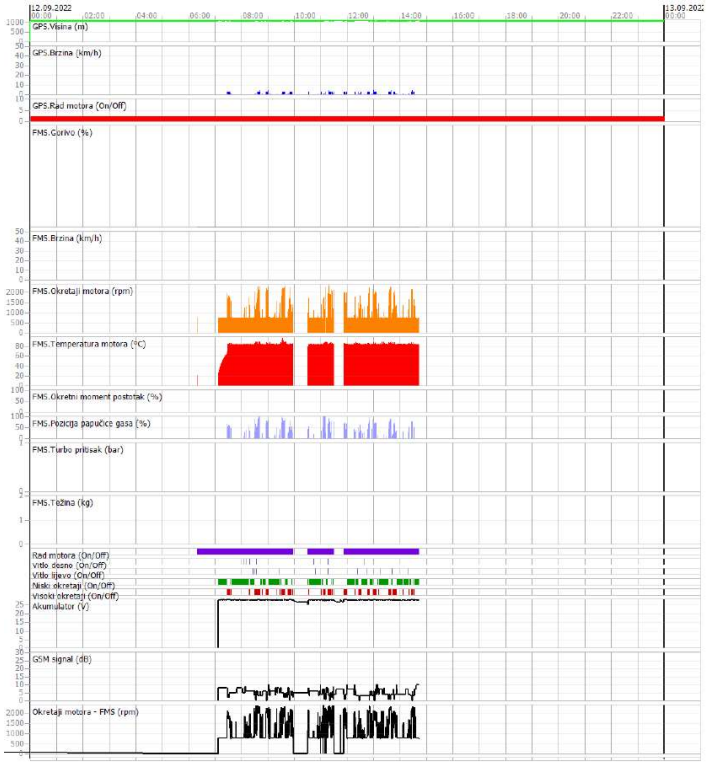
DATA COLLECTION

Mobilisis web platform

- Vehicle operation reports (graphic and tabular display, .xlsx, .pdf)







RESEARCH METHOD

- merging all data into a database
- data processing and analysis
- start and end times of each working cycle as well as each working element per cycle were determined.
- values of the diesel fuel consumed measured in mililiters via the differential flowmeter was distributed based on measured time to working cyles and working elements.

Energy consumption of skidder per days, working cycles and work elements is expressed in kWh.

1 litre of diesel fuel has a specific energy of 38 MJ or 10.56 kWh.

RESEARCH RESULTS

- 16 working days were recorded (101 skidding cycles)
- skidder extracted 211.06 m^3 of wood
- 485.01 liters of diesel fuel

Skid trail lenght: 900 m
Average skidding distance = 450 m

Skid trail average slope: + 8 %

Downhill – travel with timber load

Skidder energy consumption per day

Days	Working time, h:min	Fuel consumption, L	Energy consumption, kWh
1	7:29	30.39	320.92
2	6:32	28.04	296.10
3	6:05	26.38	278.57
4	6:28	29.39	310.31
5	2:32	11.08	116.95
6	5:54	21.79	230.05
7	2:52	13.97	147.52
8	6:47	31.36	331.14
9	6:57	42.29	**446.58**
10	6:31	38.47	406.19
11	7:09	39.64	418.55
12	6:36	31.27	330.21
13	6:59	36.50	385.44
14	6:05	34.42	363.52
15	6:25	37.31	394.01
16	6:41	32.73	345.67
Total	98:02	485.01	5121.74
Minimum	2:32	11.08	116.95
Maximum	7:29	42.29	446.58

RESEARCH RESULTS

Average fuel and energy consumption of the skidder by work elements

Work element	Average fuel consumption, L	Minimum fuel consumption, L	Maximum fuel consumption, L	Average energy consumption, kWh	Minimum energy consumption, kWh	Maximum energy consumption, kWh
Unloaded travel	1.75	0.50	3.61	18.45	5.28	38.12
Timber winching	1.19	0.49	2.76	12.58	5.17	29.15
Loaded travel	0.79	0.23	1.87	8.30	2.43	19.75
Unloading at landing	0.84	0.30	2.64	8.89	3.22	27.88

Skidder energy consumption per day and work elements

Days	Energy consumption, kWh				
	Work elements				
	Unloaded travel	Winching	Loaded travel	Unloading	Total
1	127,72	91,82	33,42	67,95	320,92
2	110,09	98,10	34,64	53,28	296,10
3	99,05	75,87	50,32	53,33	278,57
4	91,82	102,48	48,36	67,64	310,31
5	29,52	38,39	18,48	30,57	116,95
6	43,56	99,26	42,98	44,25	230,05
7	46,52	38,81	30,89	31,31	147,52
8	109,98	77,62	68,38	75,17	331,14
9	166,48	95,15	90,50	94,46	446,58
10	196,68	74,29	81,47	53,75	406,19
11	180,10	92,24	74,24	71,97	418,55
12	142,56	81,52	51,00	55,12	330,21
13	154,60	93,24	60,19	77,40	385,44
14	159,09	**100,31**	46,94	57,18	363,52
15	181,17	76,35	81,48	55,02	394,01
16	135,27	97,94	58,08	54,37	345,67
Total	1974,20	1333,40	871,37	942,77	5121,74

RESEARCH RESULTS

The total collection of data from the skidder, under real operating conditions, is still in progress to cover a period of more than 250 working days.

All measurement data collected over a long period of time were used in the simulation model.

Using simulation drive models with defined working cycles obtained by measurement, the structure of the hybrid drive and the dimensions of the hybrid drive elements (internal combustion engine, electric motor, batteries...) are determined using modern optimization methods which, as a result, give the optimal hybrid drive of the skidder for the selected working cycles (e.g. for hilly or mountainous terrain, or for universal use).

The results of energy consumption from the simulation model are compared with the calculated and displayed values of measured energy consumption by working days and work components.

CONCLUSIONS

- Determination of the energy consumption of different types of forest vehicles performing different work tasks under different terrain conditions is a very important topic of scientific research in the field of forestry engineering. These data could be used as a basis for the development of hybrid and electric forest vehicles.

- When analyzing energy consumption for the purpose of modelling a hybrid skidder drive, the key values are the maximum values.

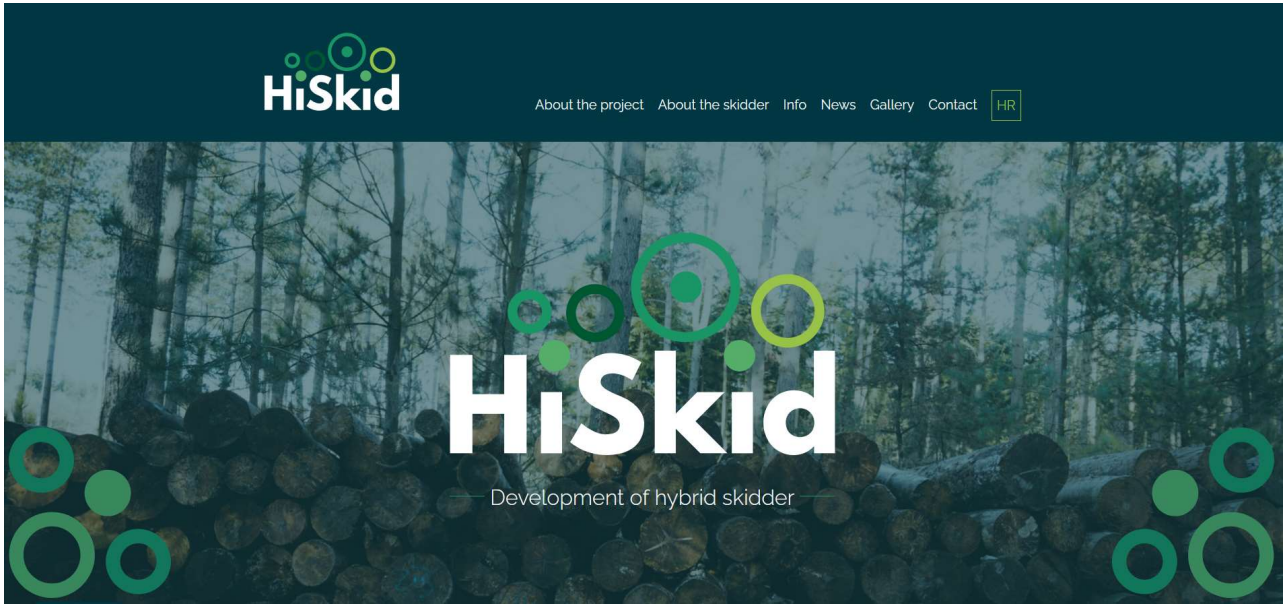
- The future hybrid drive must satisfy the need for energy in all operating conditions, including the most demanding situations that may occur when the skidder is operating in extreme conditions.

- This is the reason why long-term monitoring and measurement of energy consumption is necessary in order to detect extreme situations and measure the highest energy consumption per working day, per skidding cycle and per individual work operation.

CONCLUSIONS

- Weight of battery will not represent a problem regarding the load on the chassis, especially if you take into account that the weight of the vehicle itself exceeds 8 tons.
- Furthermore, if the additional mass is properly distributed, it is possible to achieve better traction characteristics and improved driving stability on a sloped route.
- Detailed description of the hybrid drive components, working regimes and management strategy will be presented in the following publications.

THANK YOU FOR ATTENTION!



www.hiskid.hr