NFPA Fluid Power Vehicle Challenge

NFPA Education and Technology Foundation

FINAL PRESENTATION
Purdue University
Andrea Vacca
4/13/2018

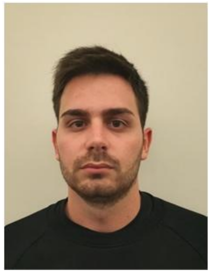
Purdue University

PRESENTATION OVERVIEW

- The Team
- Bicycle Design
  - Hydraulic design
    - AMESim simulation and optimization
    - Experimental and simulation results
  - Mechanical design
    - Static analysis
    - Final design
  - Electronic design
    - Application design and functionalities
- Conclusion
  - Experimental results
  - Cost analysis
  - Lesson learned

The team

Francesco Leschiera (Italy)



Jiongyu Sun (China)

Marcos Ivan Mireles (Mexico)

Jeffrey Kuhn (U.S.A.)

Team advisor

Andrea Vacca

Team Advisor

Professor of Mechanical Engineering and Agricultural & Biological Engineering
Maha Fluid Power Research Center
Purdue University

Presentation highlight

External gear pump

Gerotor pump

Which is the best hydraulic unit for use in a human powered vehicle?

Internal gear pump

Piston pump

Hydraulic design

Goal : Find the most efficient hydraulic units for the design

- Hydraulic units comparison
  - ❖Hydraulic layout
  - ❖Operating modes
  - ❖AMESim circuit
  - ❖Optimization process
  - ❖Results

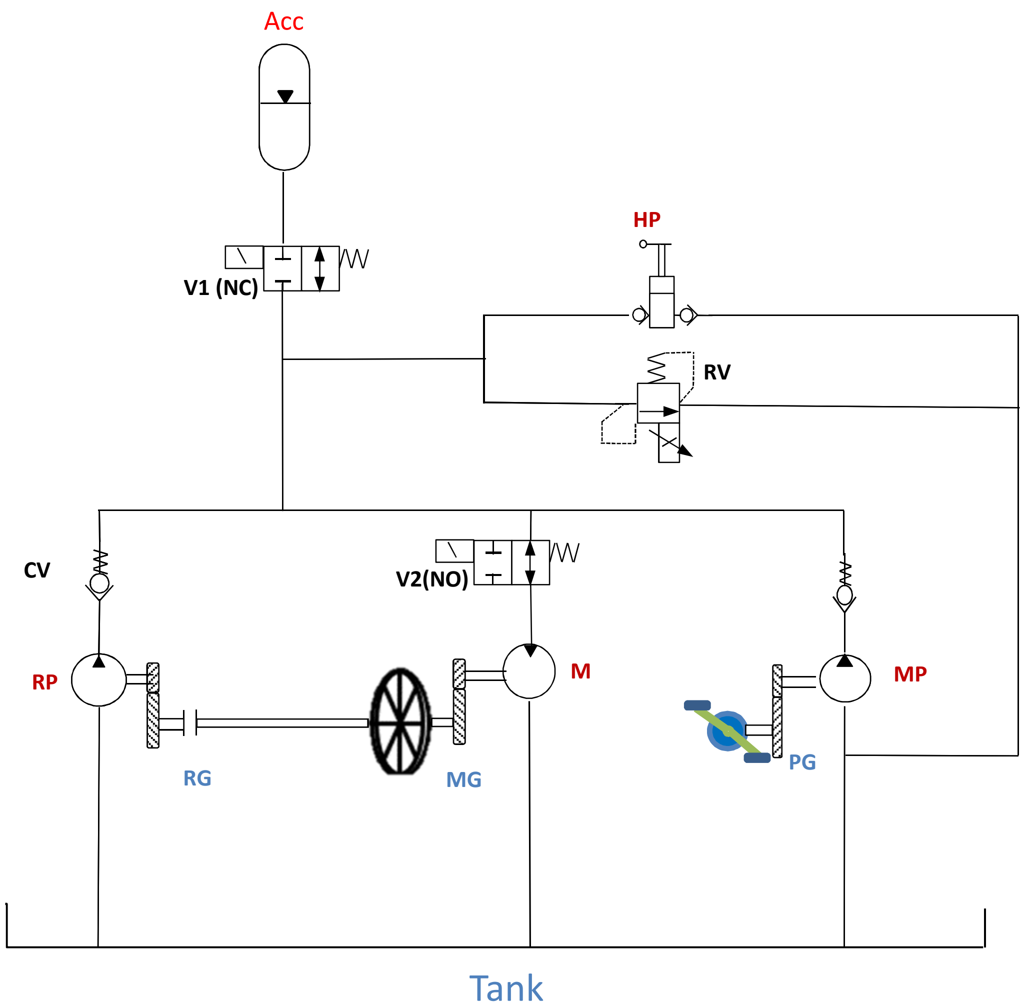
Hydraulic unit comparison

NFPA Fluid Power

Hydraulic Units

PISTON PUMP/MOTOR	GEAR PUMP/MOTOR
Higher efficiency	Lower efficiency
Contamination	Contamination resistant
Heavier (cast iron)	Lighter (aluminum)
Higher max pressure	Compact packaging
Cost inefficient	Cost efficient
Parker F-11	Casappa PLP
Bent axis piston pump	External gear pump

Hydraulic circuit layout



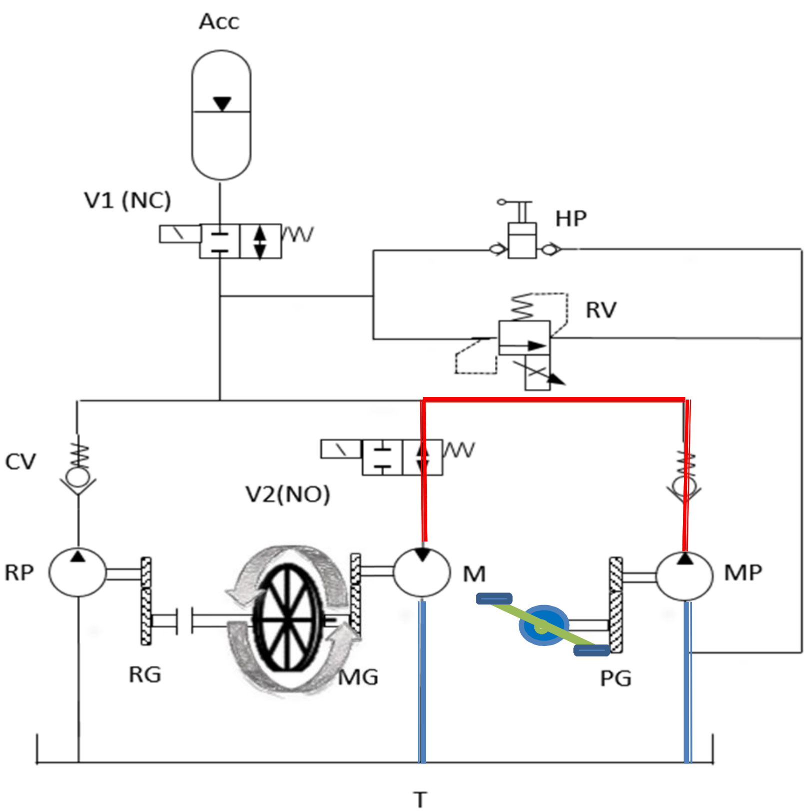
Valves
- V1: Directional Control Valve (Normally Closed)
- RV: Relief Valve
- CV: Check Valve
- V2: Directional Control Valve (Normally Open)

Gears
- RG: Regeneration Gear
- MG: Motor Gear
- PG: Pump Gear

Pump

Motor
- M: Motor
- MP: Main Pump
- HP: Hand Pump
- RP: Regeneration Pump
- Acc: Accumulator

Operating modes : Pedaling

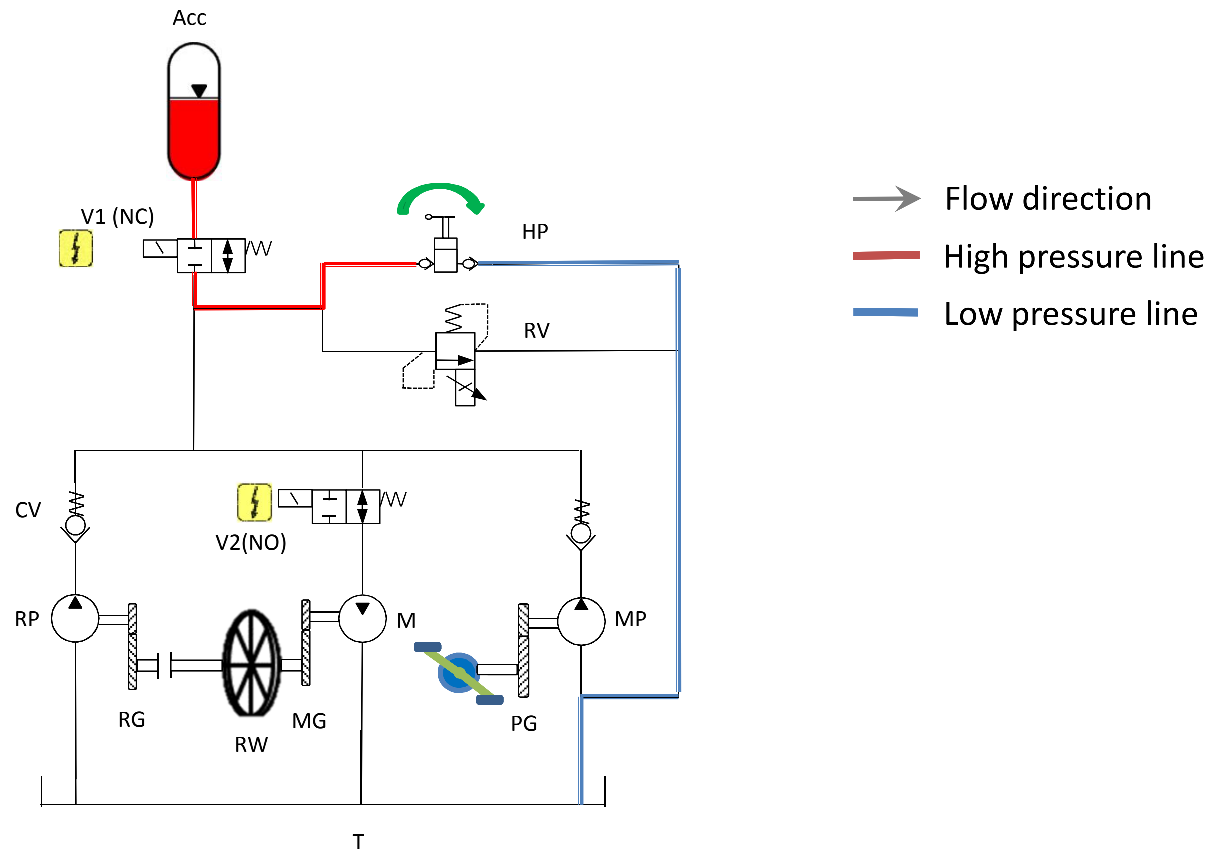


Flow direction

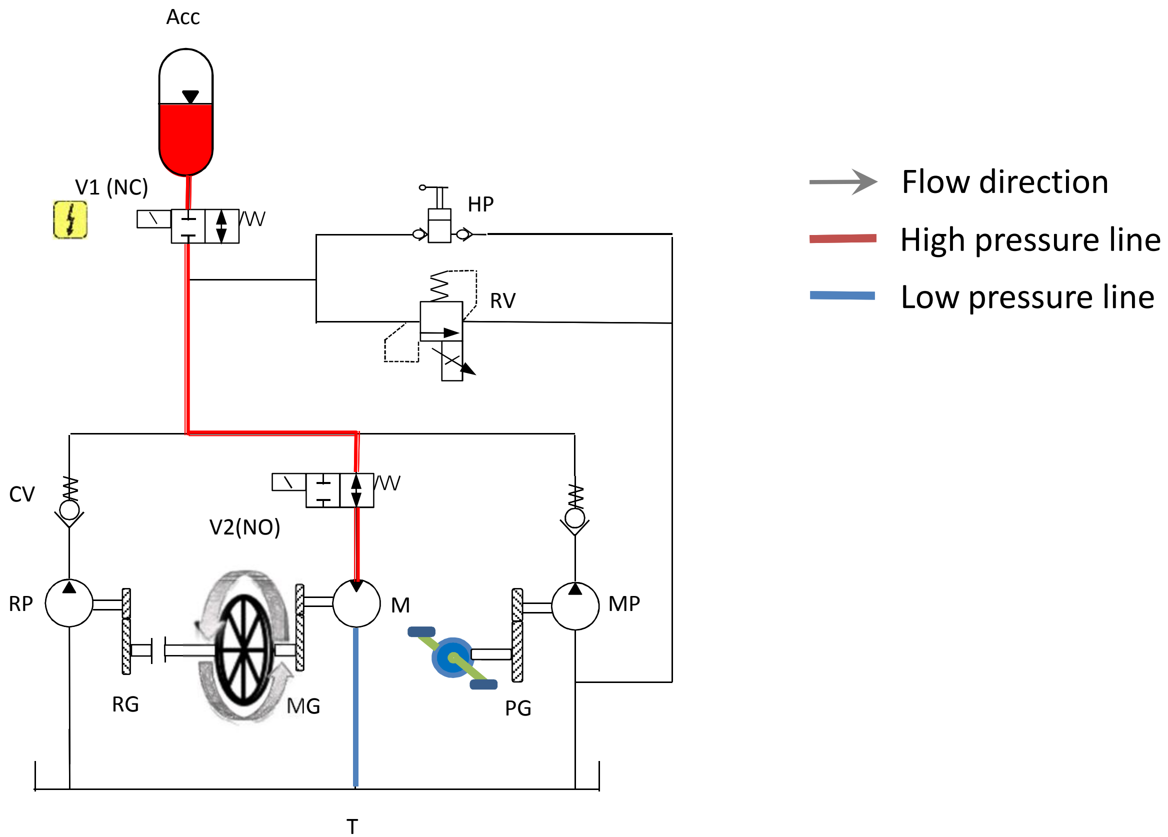
High pressure line

Low pressure line

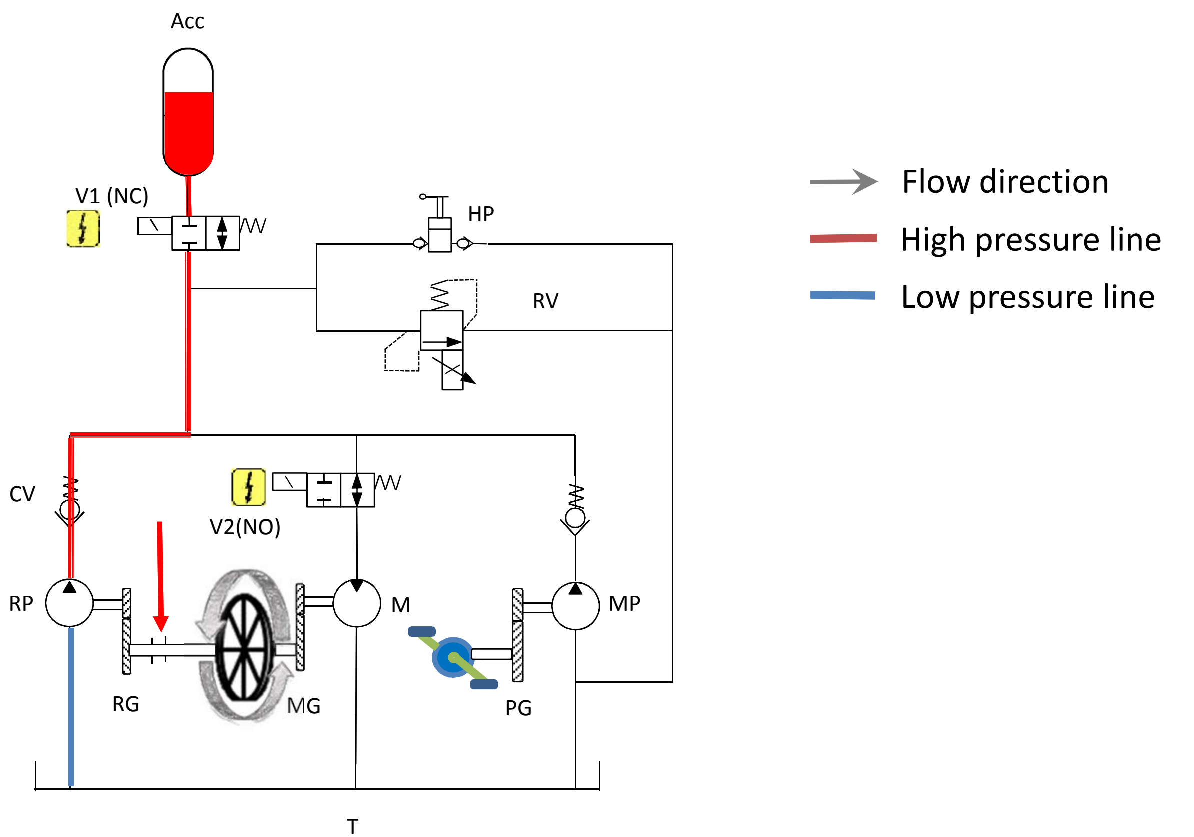
Operating modes : Charging



Operating modes : Boost



Operating modes : Regeneration



Pedaling mode: Sizing

Data	Name	Data
θ	Slope	1% grade
r	Wheel Radius	0.324 m
f	Rolling Resistance	0.006
n	Rotational Speed	70 rpm

Goal : Max velocity

Assumption	Name	Value
$\eta_{hm,m}$	Motor Hydro-mechanic Efficiency	0.9
$\eta_{v,p}$	Pump Volumetric Efficiency	0.9
$\eta_{hm,p}$	Pump Hydro-mechanic Efficiency	0.9
$\eta_{v,m}$	Motor Volumetric Efficiency	0.9
P	Pressure	50 bar

4 design variables + 5 assumption value → Velocity

Design Variable	Name
V_m	Motor Displacement
g_p	Gear Ratio (Pump)
v_p	Pump Displacement
g_m	Gear Ratio (Motor)

The resistance force would apply a torque on the shaft

$$T_m = Frg_m$$

Assuming a line pressure is p, the motor displacement is,

$$V_m = \frac{T_m}{p \cdot \eta_{hm,m}}$$

and the pump displacement is,

$$V_p = \frac{T_p \cdot \eta_{hm,p}}{p}$$

With a shaft rotational speed of n, the flow rate Q is,

$$Q = \eta_{v,p} \cdot n \cdot V_p \cdot g_p$$

The linear velocity of the vehicle would be,

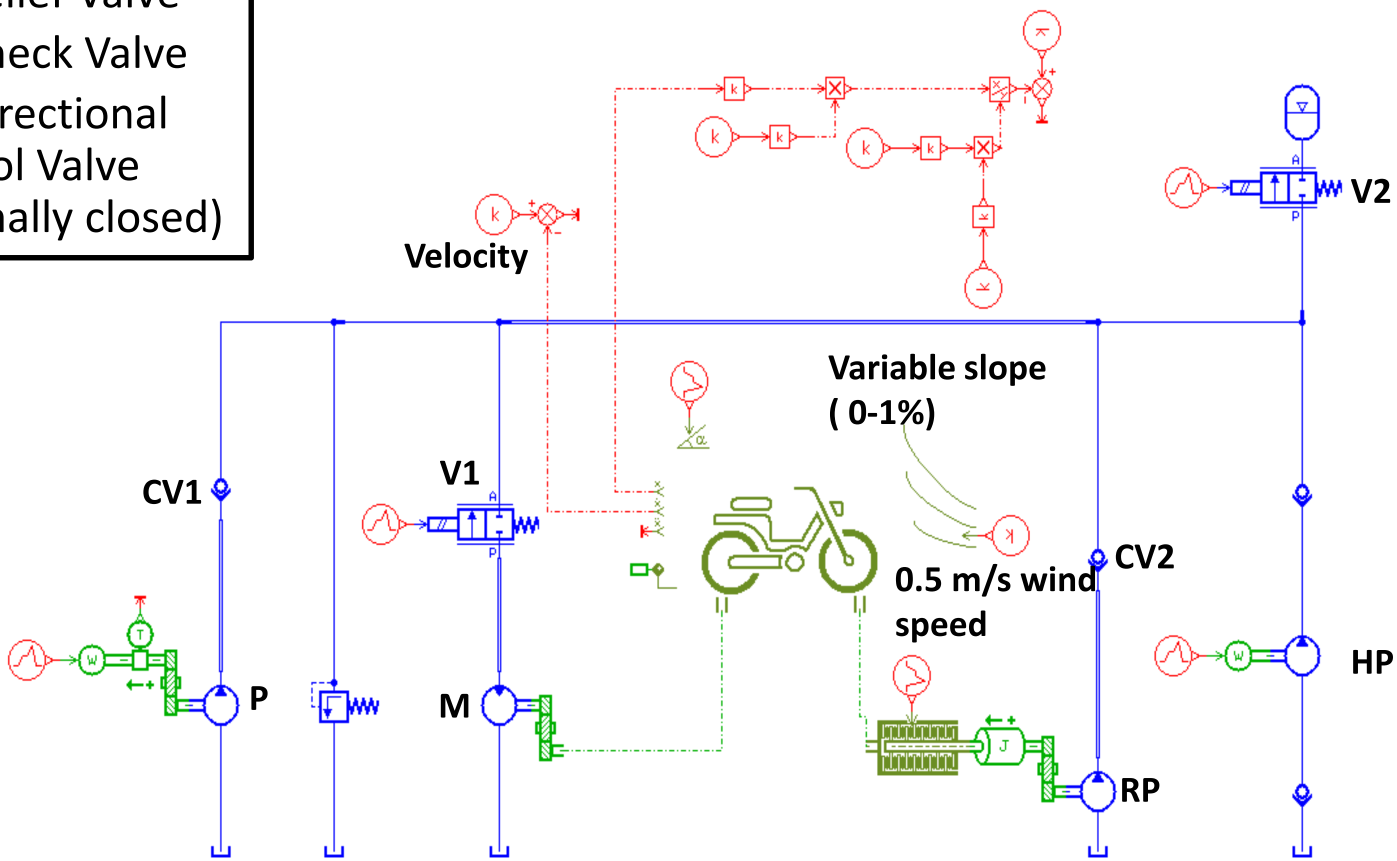
$$v = \frac{\eta_{v,m} \cdot Q}{V_m} \cdot 2\pi r \cdot g_m$$

AMESim circuit

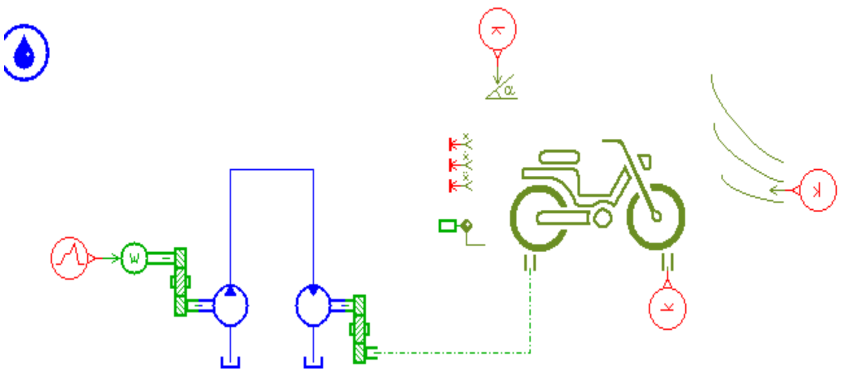
- V1: Directional Control Valve (Normally open)
- RV: Relief Valve
- CV: Check Valve
- V2: Directional Control Valve (Normally closed)

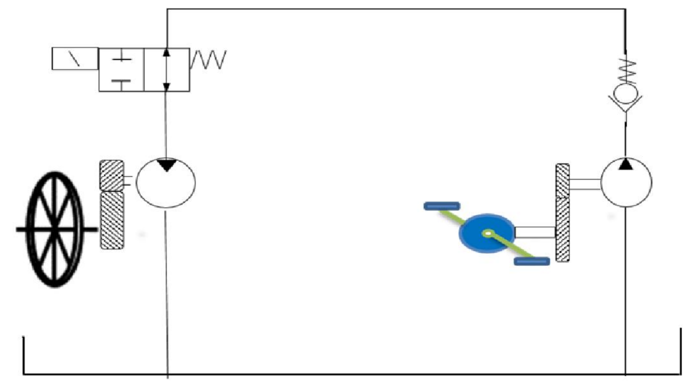
- RG: Regeneration Gear
- MG: Motor Gear
- PG: Pump Gear

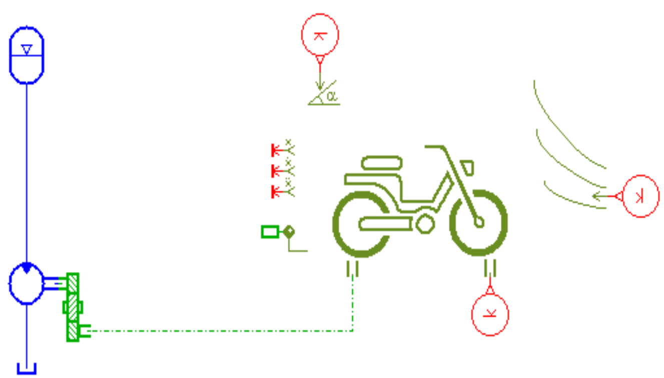
- M: Motor
- MP: Main Pump
- HP: Hand Pump
- RP: Regeneration Pump
- ACC: Accumulator

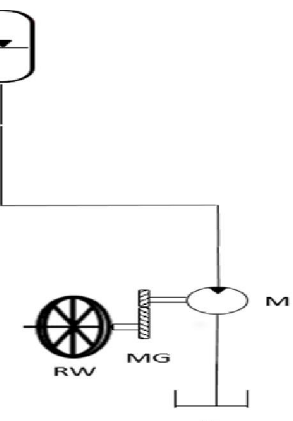


Optimization circuit

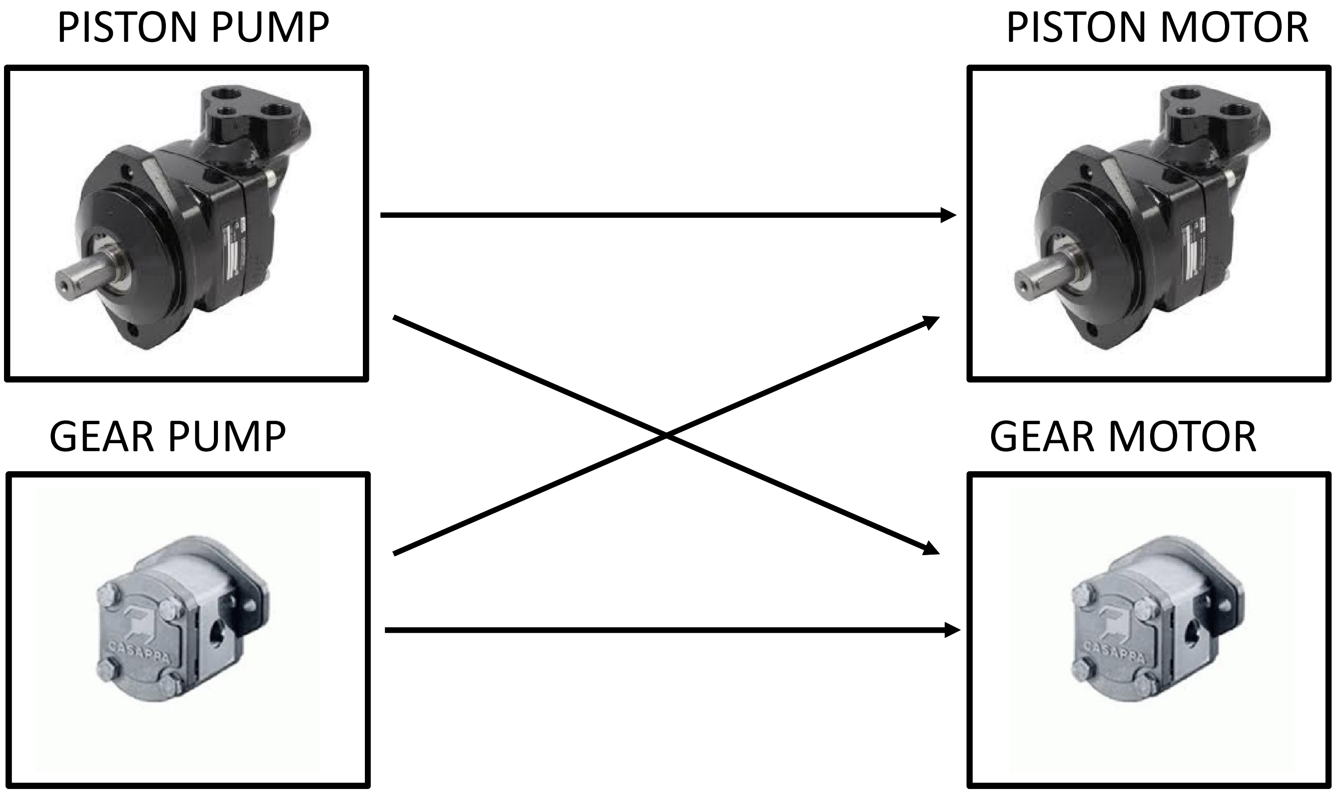




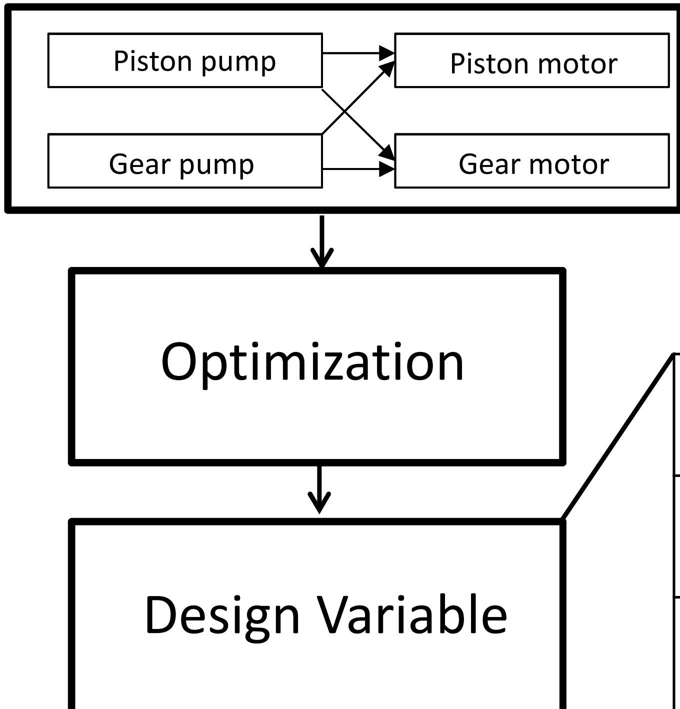




Hydraulic units combinations

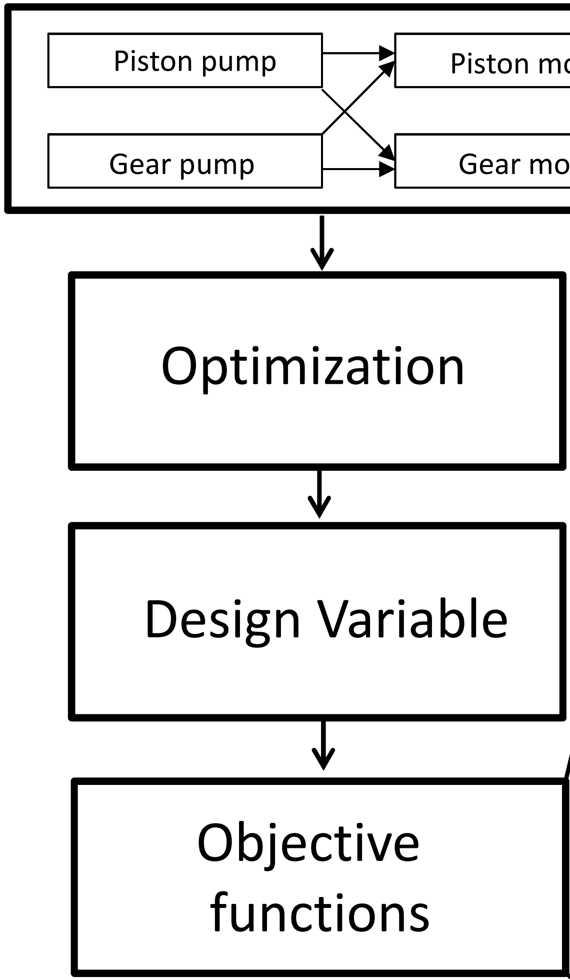


Optimization flow process



Design Variable	Range	Lower bound	Upper bound
Pump displacement	Changing	1 / 4.9	10 / 19
Motor displacement	Changing	1 / 4.9	10 / 19
Pump gear ratio	Not changing	1	20
Motor gear ratio	Not changing	-1	20

Optimization flow process



Torque constrain = 27Nm

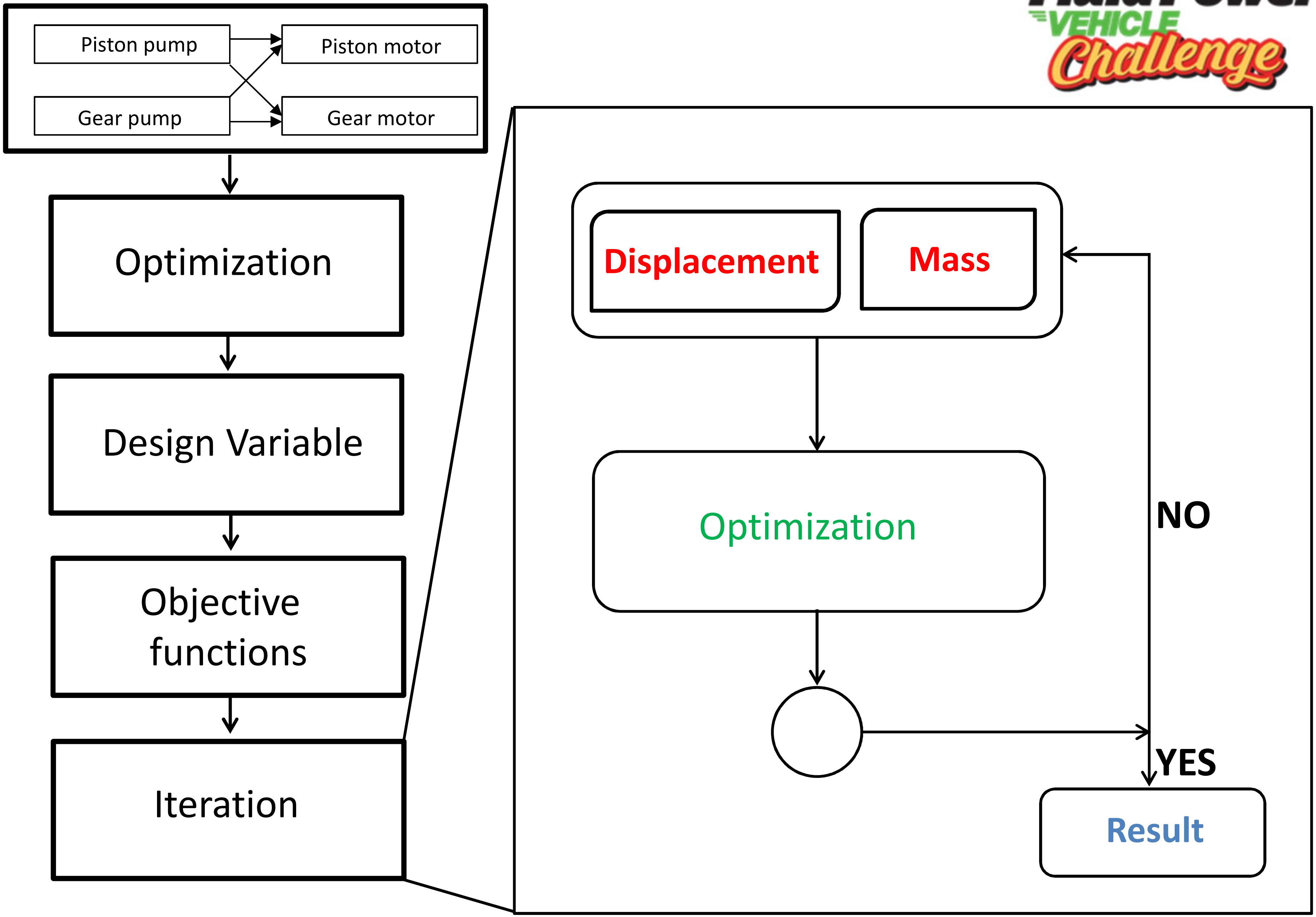
Objective functions	**Algorithm**	**Refine**
Velocity	NLPQL*	Velocity+Scoring ratio/20
Scoring Ratio		

***Non-Linear Programming by Quadratic Lagrangian**

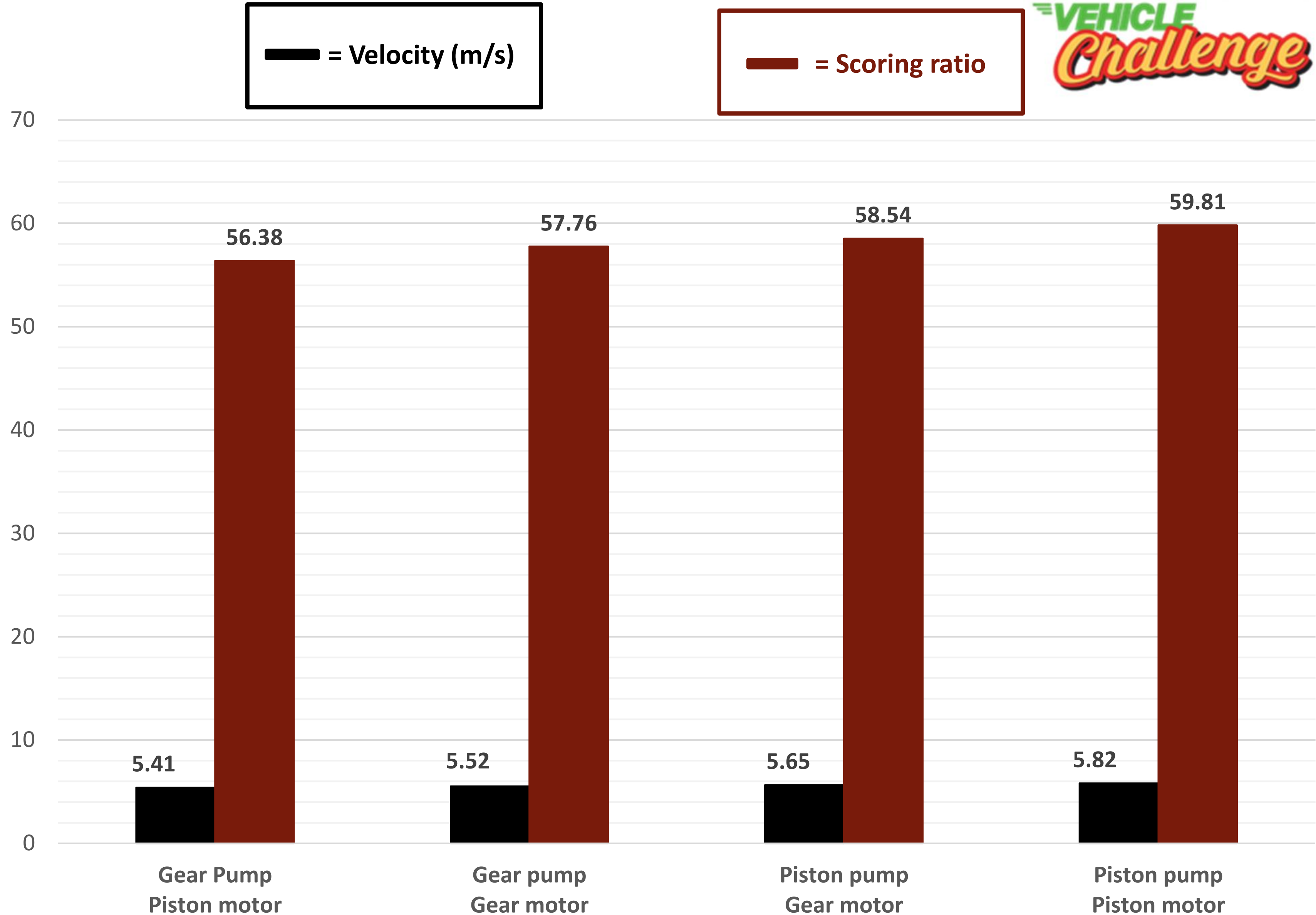
The algorithm uses a quadratic approximation of the Lagrangian function

It is available only for continuous be derivable input parameters and can only handle one output parameter (other output parameters can be defined as constraints).

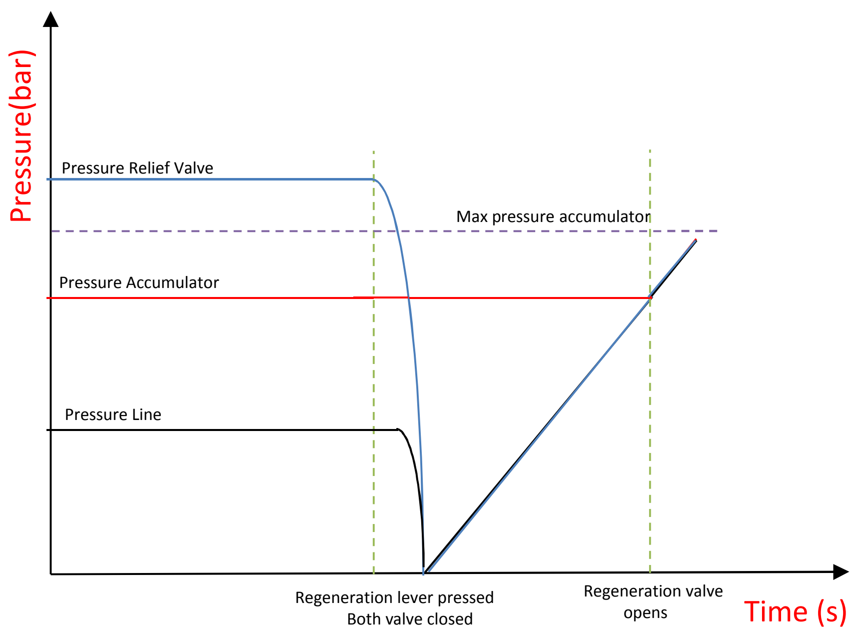
Optimization flow process

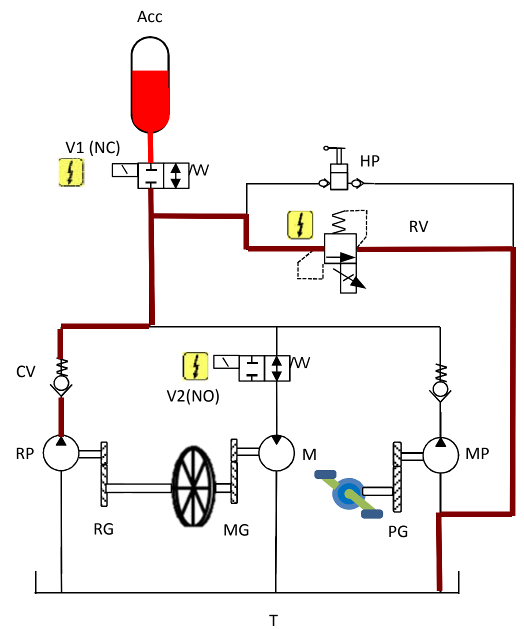


Simulation results



Regeneration system





Chosen components

Best Design*	Value
Pump Displacement (F-11)	5.6 cc/rev
Motor Displacement (F-11)	4.9 cc/rev
Front Gear Ratio	6.48
Rear Gear Ratio	-2.07

Selected components	Value
Piston pump F-11	4.9 cc/rev
Piston motor F-11	4.9 cc/rev
Front Gear Ratio (MISUMI)	120/19
Rear Gear Ratio (MISUMI)	100/17
Regeneration gear ratio(ANDYMARK)	2.8

Other components	Value
Accumulator	2.0 L
EATON LZJ	6.6 cc/rev
Eaton NO valve	-
Sunhydraulics NC valve	-
Parker relief valve	200 bar

Mechanical design

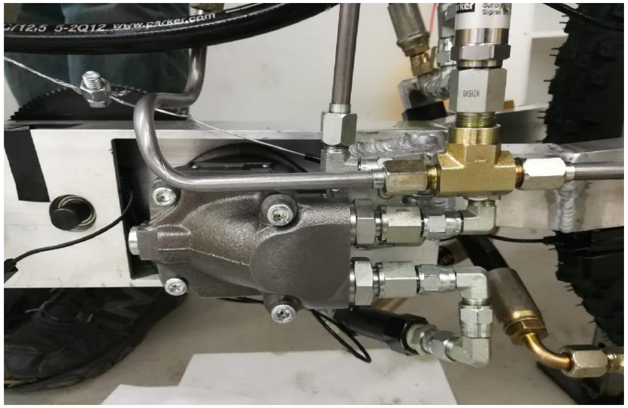
Goal : Streamline and appealing design

- Mechanical units comparison
  - ❖Hydraulic components
  - ❖Mechanical components
  - ❖Static analysis
  - ❖Final design

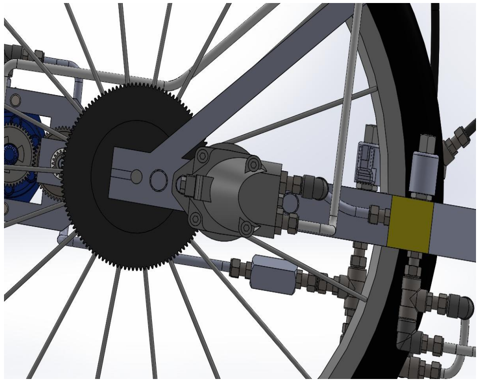
Hydraulic components

Pump / Motor Specifications	
Material	Cast iron
Displacements	4.9 cc/rev
Weight	11 lbs
Provider	Parker

Pump

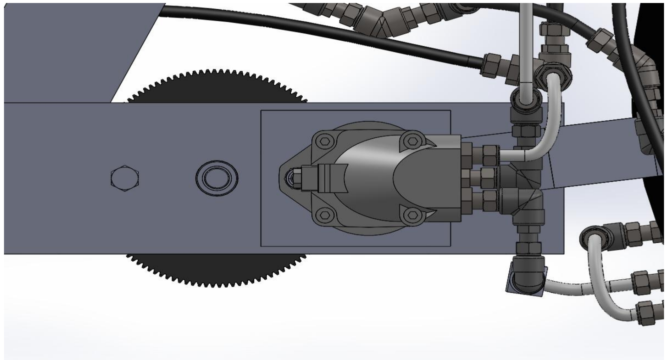


CAD Motor



Motor

CAD Pump

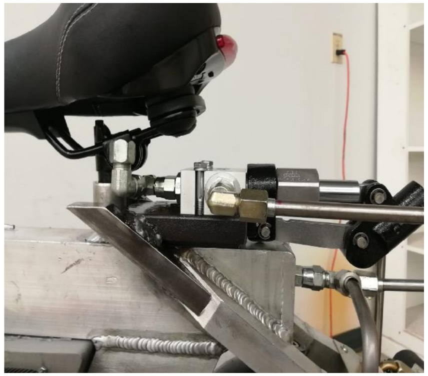


Hydraulic components

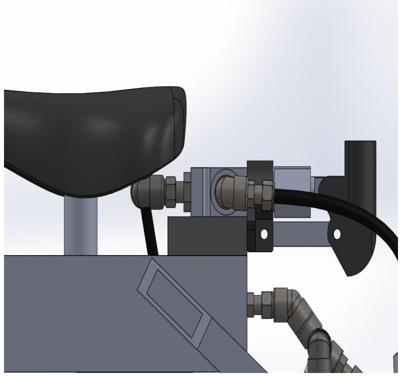
Hand pump Specifications	
Material	Steel
Displacements	4.9 cc/stroke
Weight	1.75 lbs
Provider	Hydac

Regeneration pump Specifications	
Material	Aluminum
Displacements	6.6 cc/rev
Weight	3 lbs
Provider	Eaton

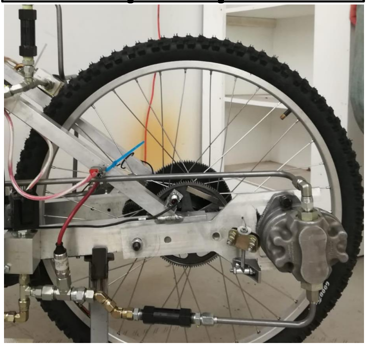
Hand pump



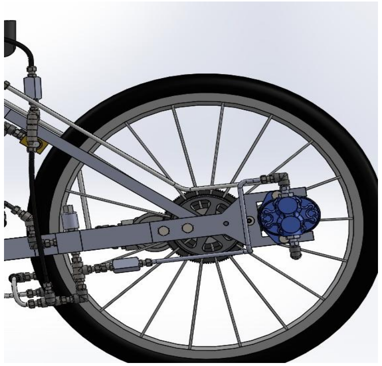
CAD Hand pump



Regeneration pump



CAD Regeneration pump



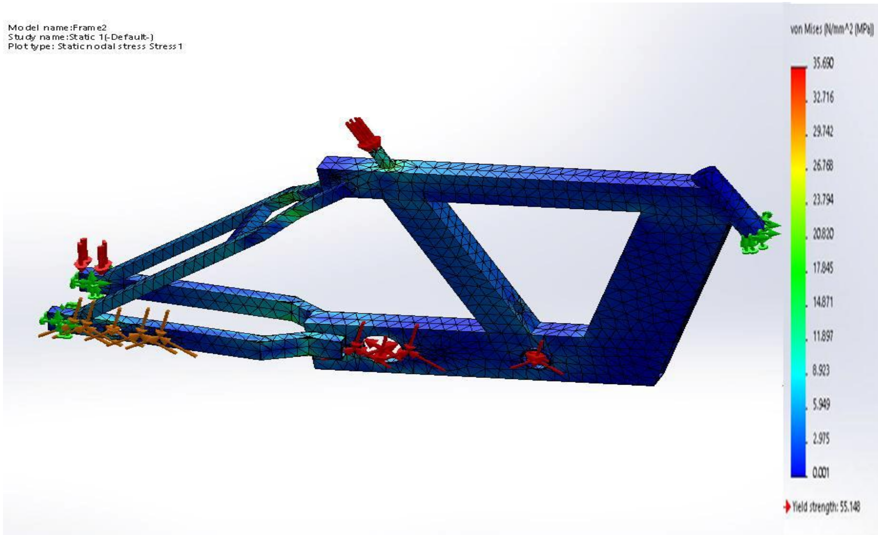
Mechanical components

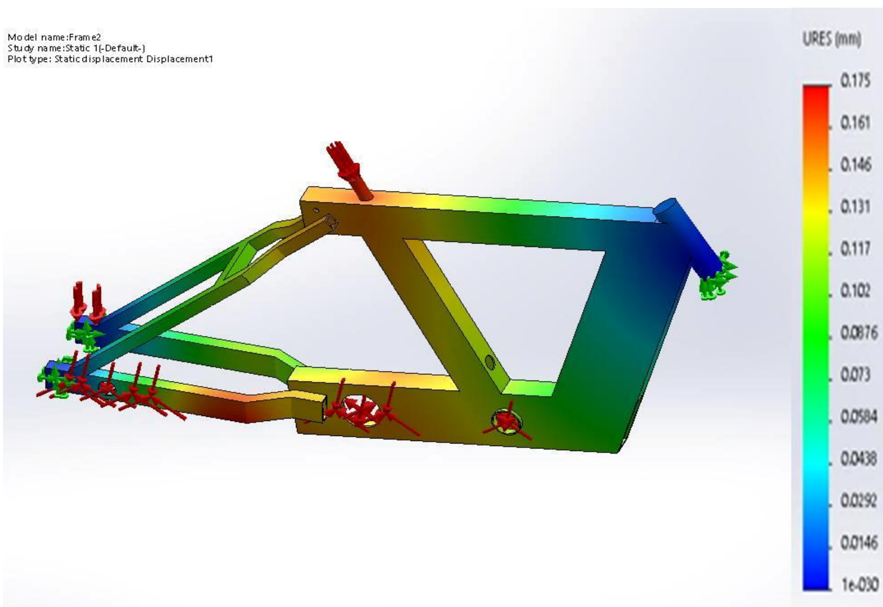
Pump Gear Box Technical Specifications	
Material	Stainless Steel
# of stages	2
Primary Gear Ratio	120/19
Secondary Gear Ratio	120/120
Provider	Misumi

Regeneration Gear Box Specifications	
Gear Material	Steel
# of stages	1
Total Gear Ratio	2.8/1

Motor Gear Box Technical Specifications	
Material	Stainless Steel
Number of Stages	1
Gear Ratio	100/17

Static analisys





Component	Weight (Kg)
Parker F-11(x2)	10
Eaton LZJ	3
Hand pump	2
Accumulator	2
Rider	90
Oil	3.5
Frame	15
Other components	3
Total	**128.5**

Final design

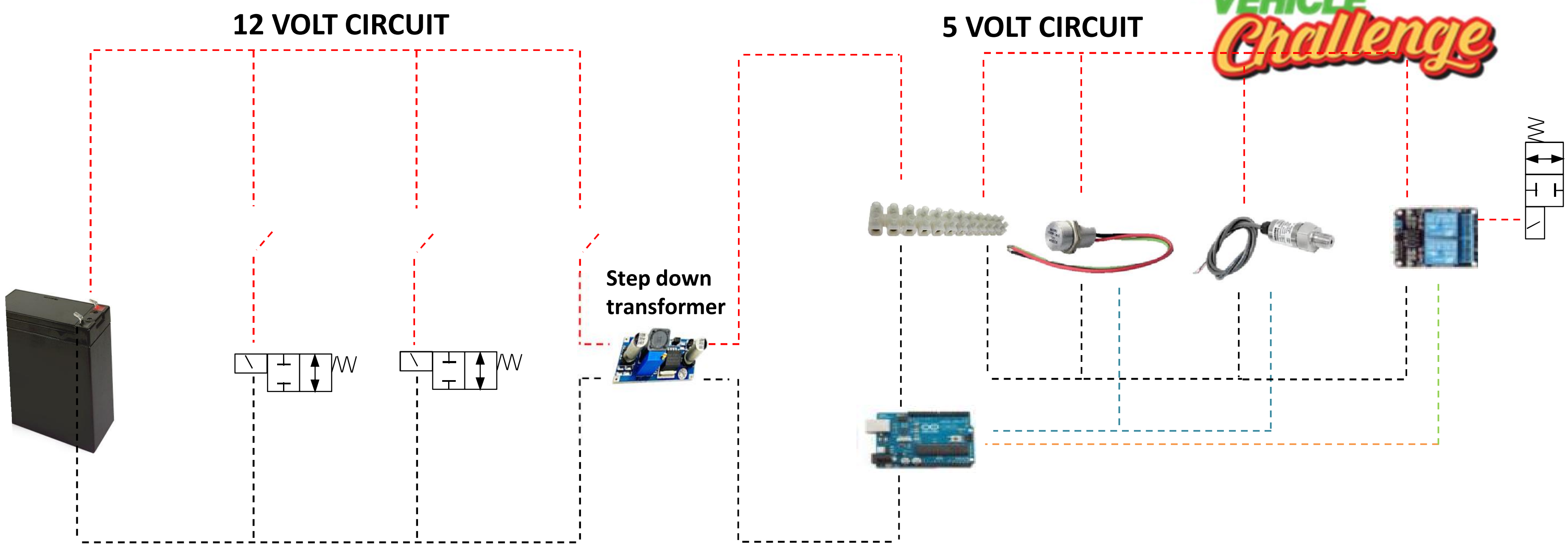
NFPA Fluid Power VEHICLE Challenge

Electrical design

Goal : Design an interactive modern

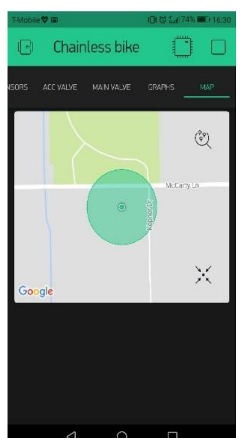
- Market available app
  - Electronic circuit
  - Functionalities
  - Extra features

Electric circuit design



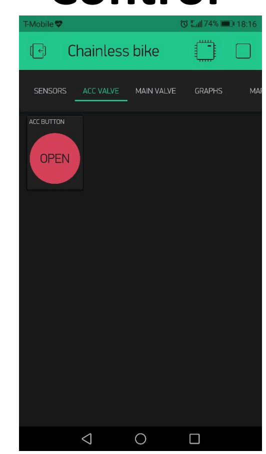
Monitoring

Localization



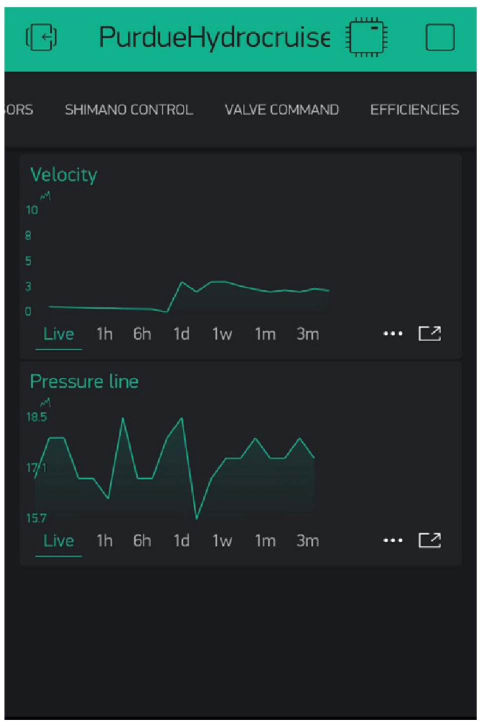
Instruction

Control



App features

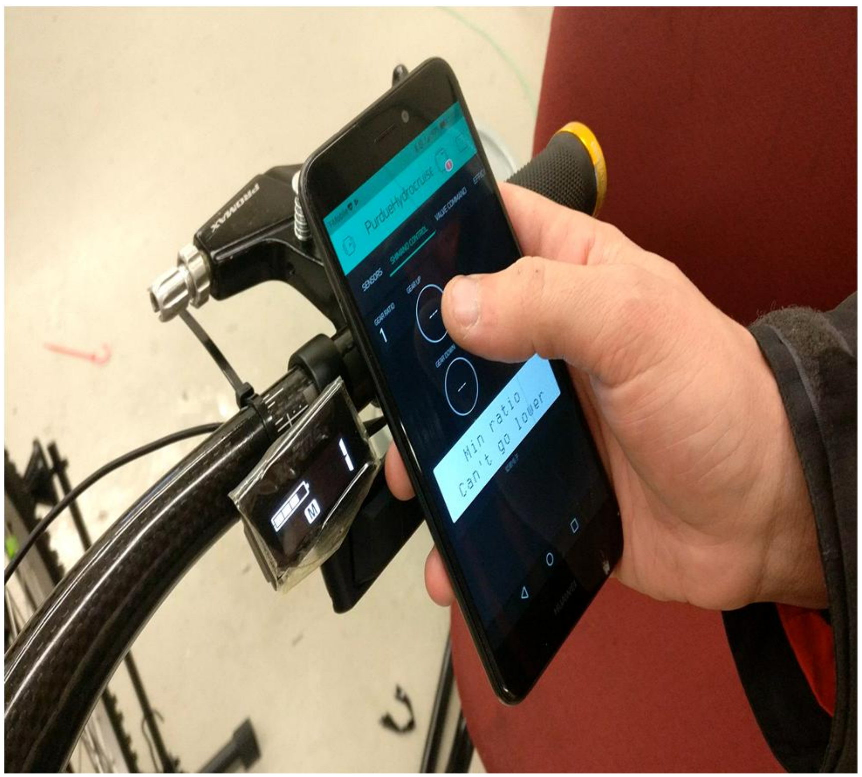
Monitoring



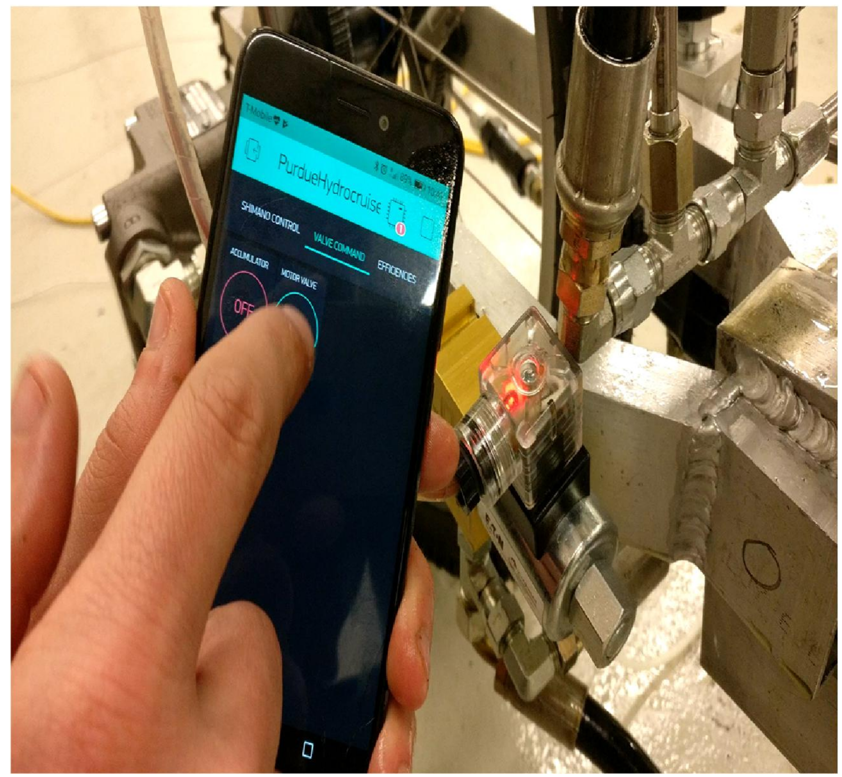
App features

Control

Shimano control



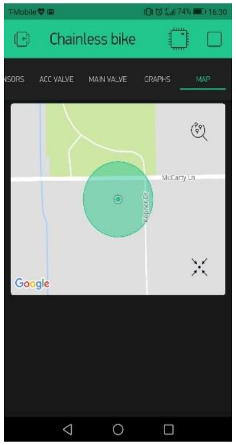
Valve control



App features

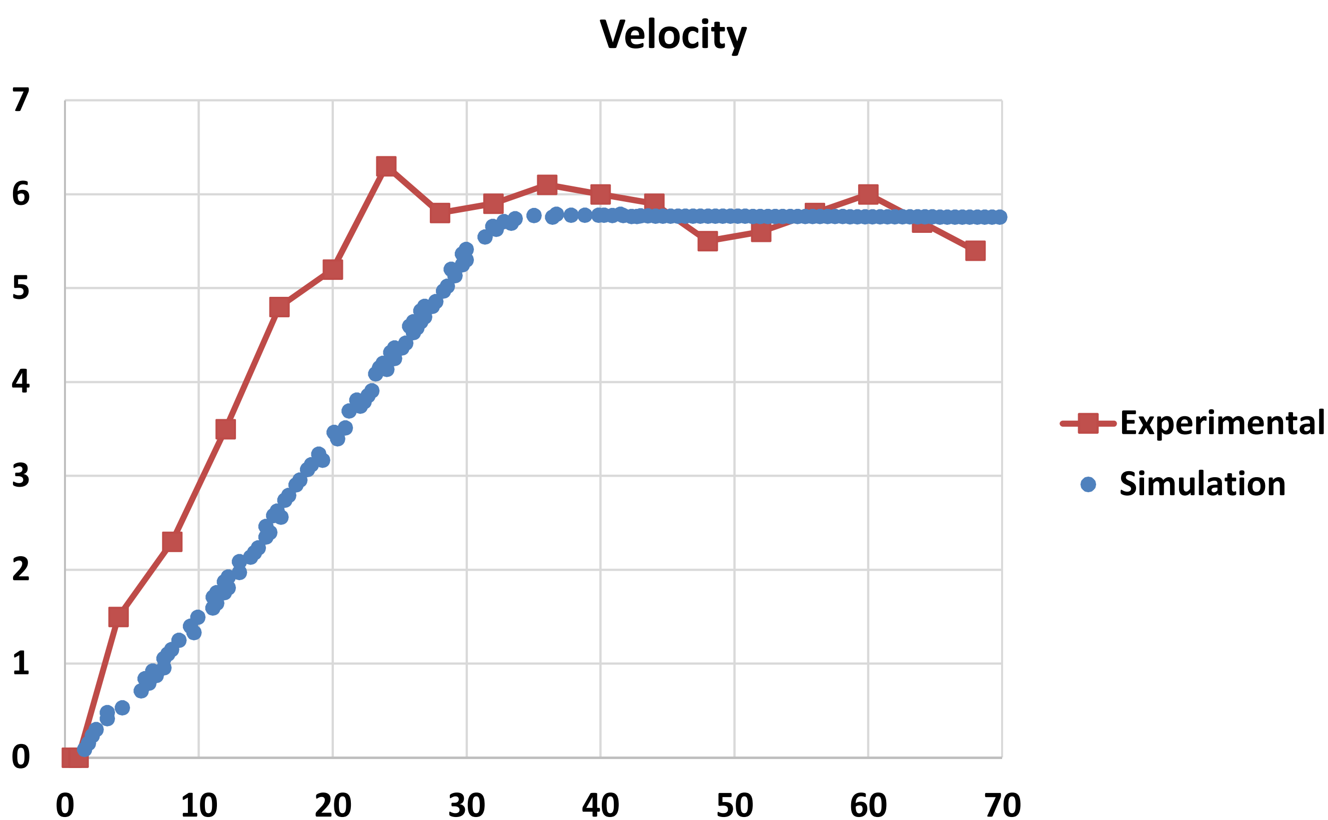
Extra features

GPS positioning



Instruction

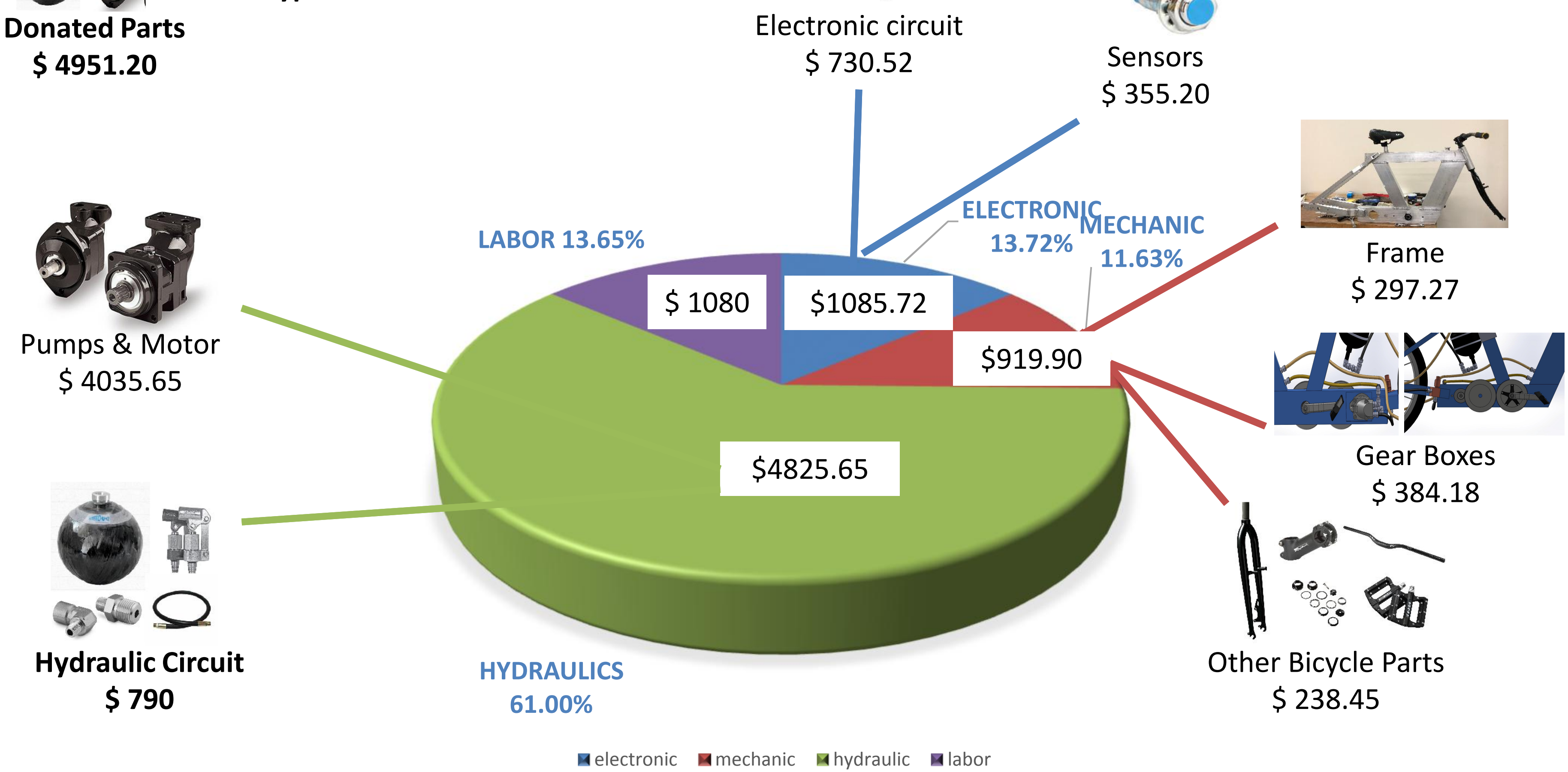
Experimental results



Cost analysis

Prototype Cost: $ 7911.27

Prototype Cost with Donation: $ 2960.07



Cost analysis

Basic Version
Cost: 2397.48

Lite Version
Cost: 3128

Feature	Cost [$]
Shimano Alfine 8 Speed	328.92
Electronic Control System	730.52
Regeneration System	530.25
Customized Painting	100

Premium Version
Cost: 3373.68

Luxury Version
Cost: 4003.93

Some lessons learned

- Budgeting management
- Time management
- Organization skills
- Theoretical knowledge learning
- Programming knowledge learning
- Team cooperation
- Problem Solving

Conclusion

We all agreed that this project was able to expand our practical/theoretical knowledge as engineers. It also challenged our problem solving abilities while incorporating elements of hydraulic controls, mechanical manufacturing, and electronic circuit analysis.

Thank You!

Questions?