Reliability of Hybrid Vehicle System

2004 Toyota Prius hybrid vehicle

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Hybrid Vehicles

Toyota Prius

Honda Civic

Hyundai Sonata

Motivation & Contribution

Motivation:

(1) Hybrid vehicles plays a pivotal role during a transitional period from conventional vehicles to electrical vehicles.

(2) A more careful analysis of the reliability of hybrid vehicles is needed based on existing literatures and people's opinions.

Contribution:

(1) Fault trees of different operation modes of hybrid vehicles are constructed.

(2) The probability of failure is estimated by applying Bayesian analysis.

Outline

I. Reliability model

1. Fault tree for different operation modes

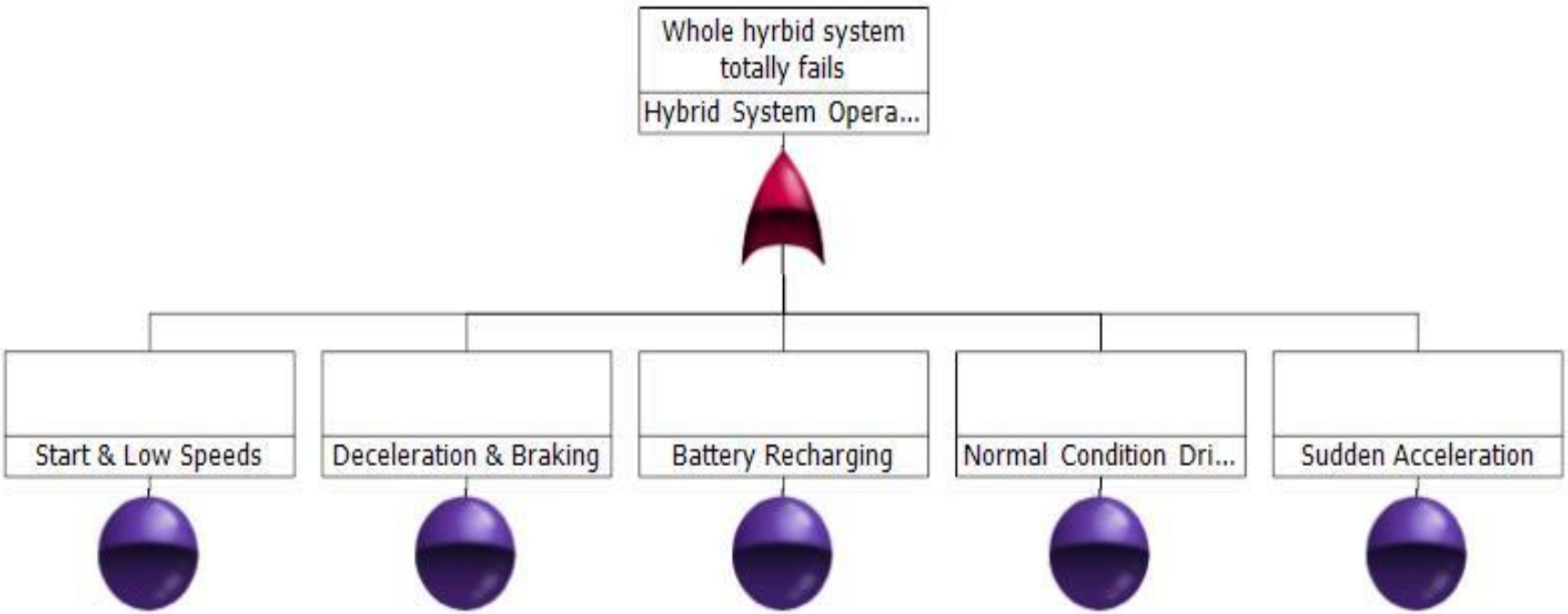
2. Estimation of failure probabilities

   (1) Exponential distribution based on the mean time to failure (MTTF)

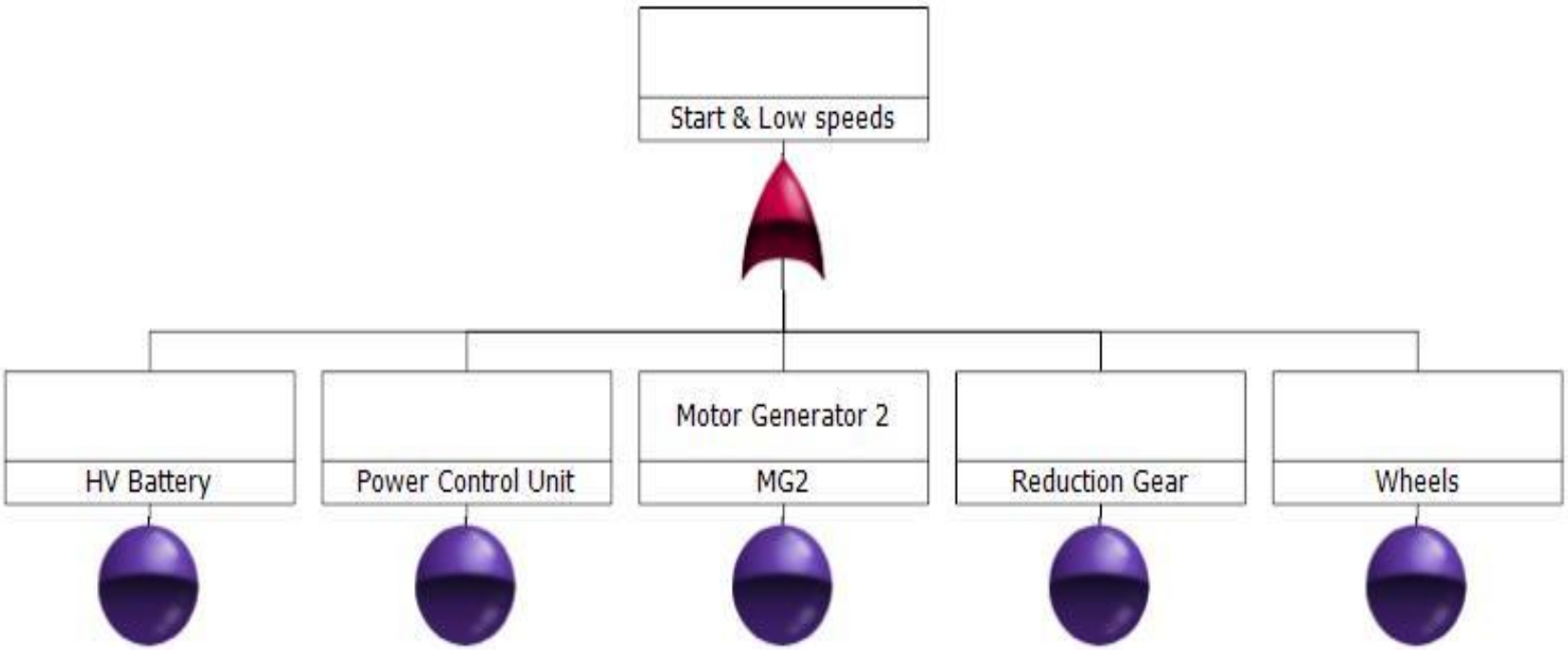
   (2) Bayesian analysis to incorporate survey data

II. Results & Discussion

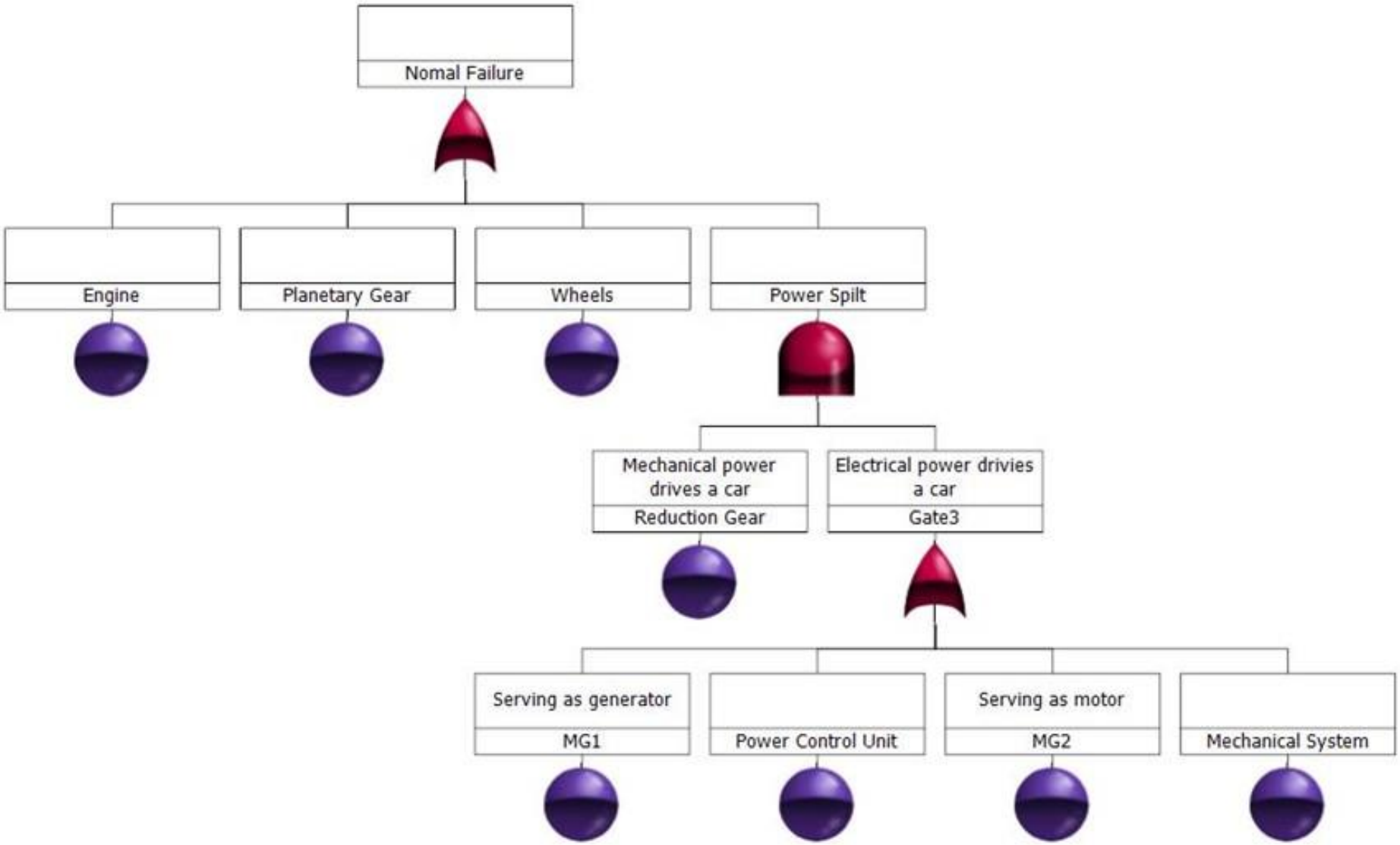
Hybrid System



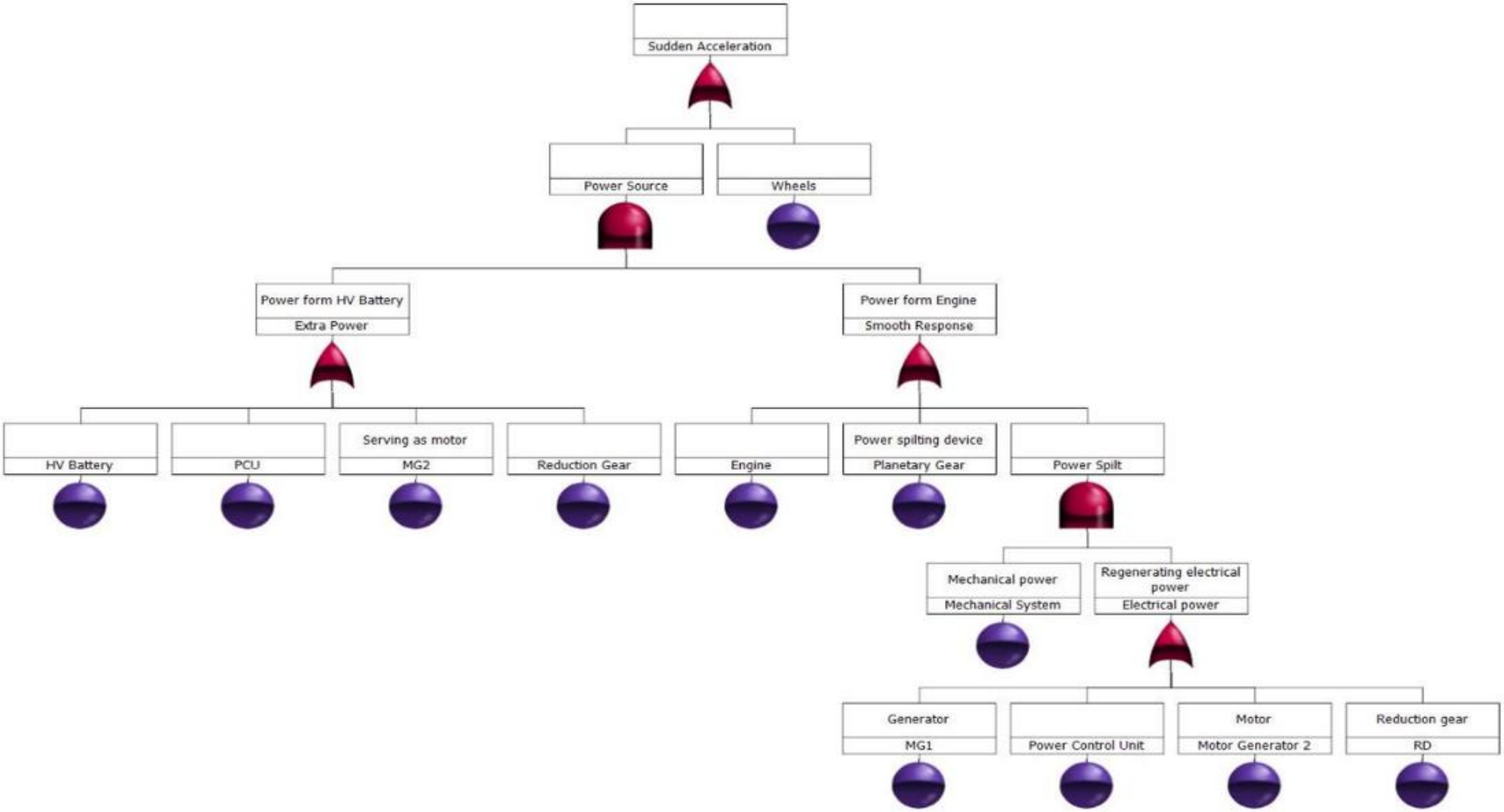
Starting and Driving at Low Speeds



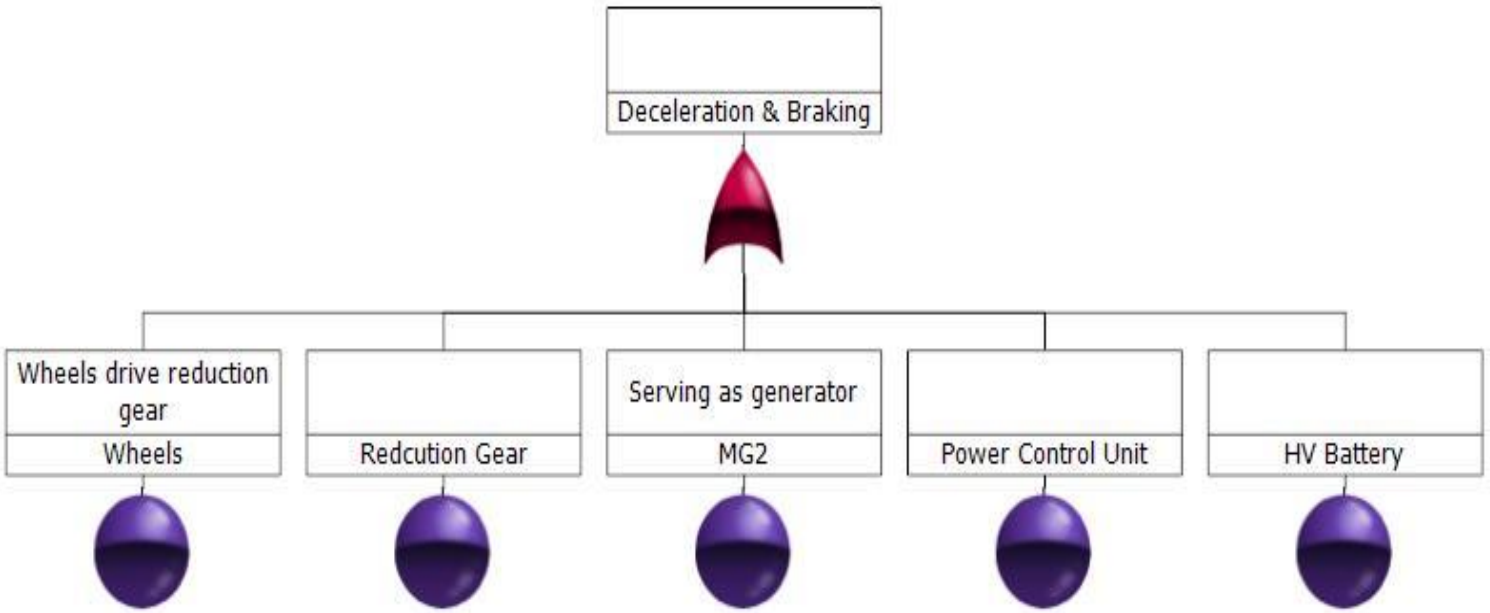
Driving Under Normal Conditions



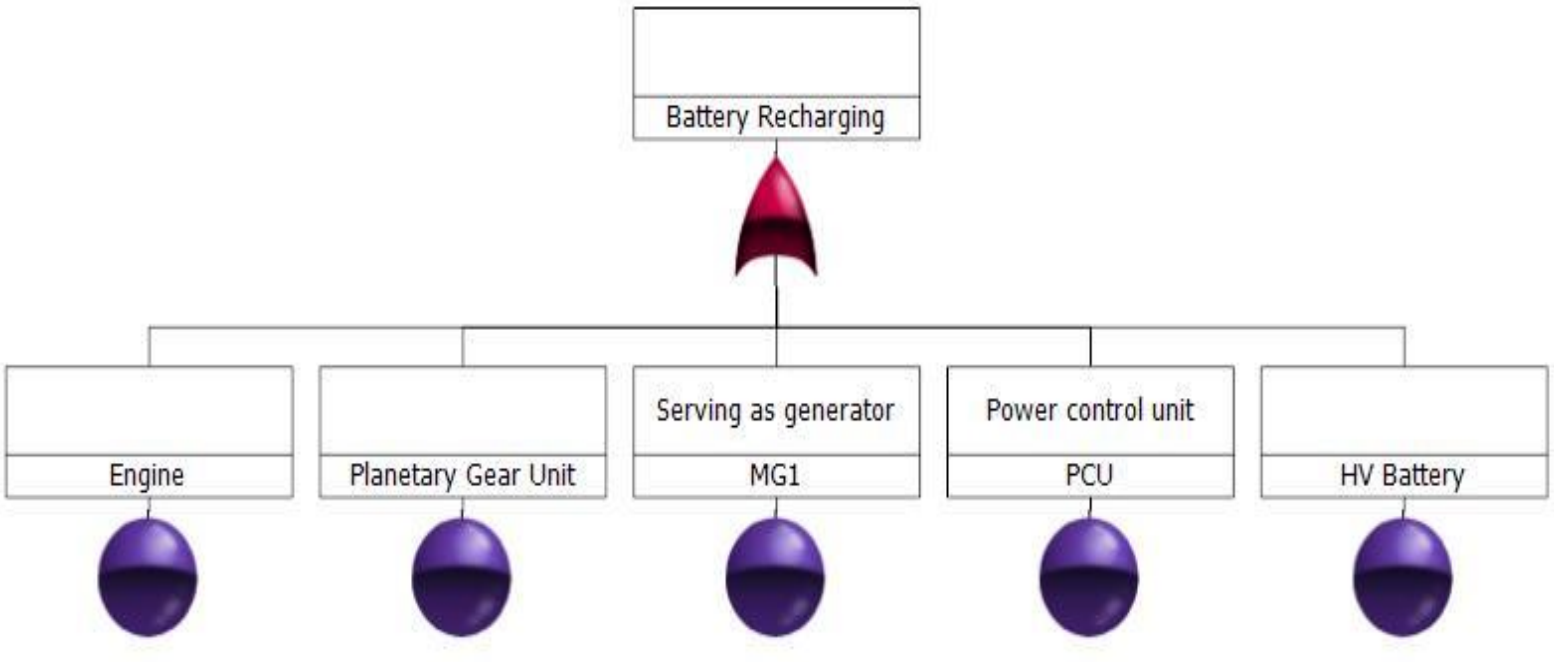
Sudden Acceleration



Deceleration and Braking



Battery Recharging



Failure Expression of Different Operation Modes

Start and low to mid-range speeds = H+P+N+R+W

Driving under normal conditions = E + G + W + R

Sudden acceleration = W + R + HE + PE + NE + GH + GP + GN

Deceleration and braking = W + R + N + P + H

Battery recharging = E + G + M + P + H

(HV Battery: H Engine: E MG1: M MG2: N Power Control Unit: P
Reduction Gear: R Planetary Gear: G Wheels: W)

Total failure in hybrid system = H+P+N+R+W+E+G+M

Standard Components

Mean time to failure (MTTF):

$$\text{MTTF} = \int_0^\infty R(t)dt = \int_0^\infty e^{-\nu t} = \frac{1}{\nu}$$

Assume reliability $R(t)$ at time t of a standard component follows an exponential distribution

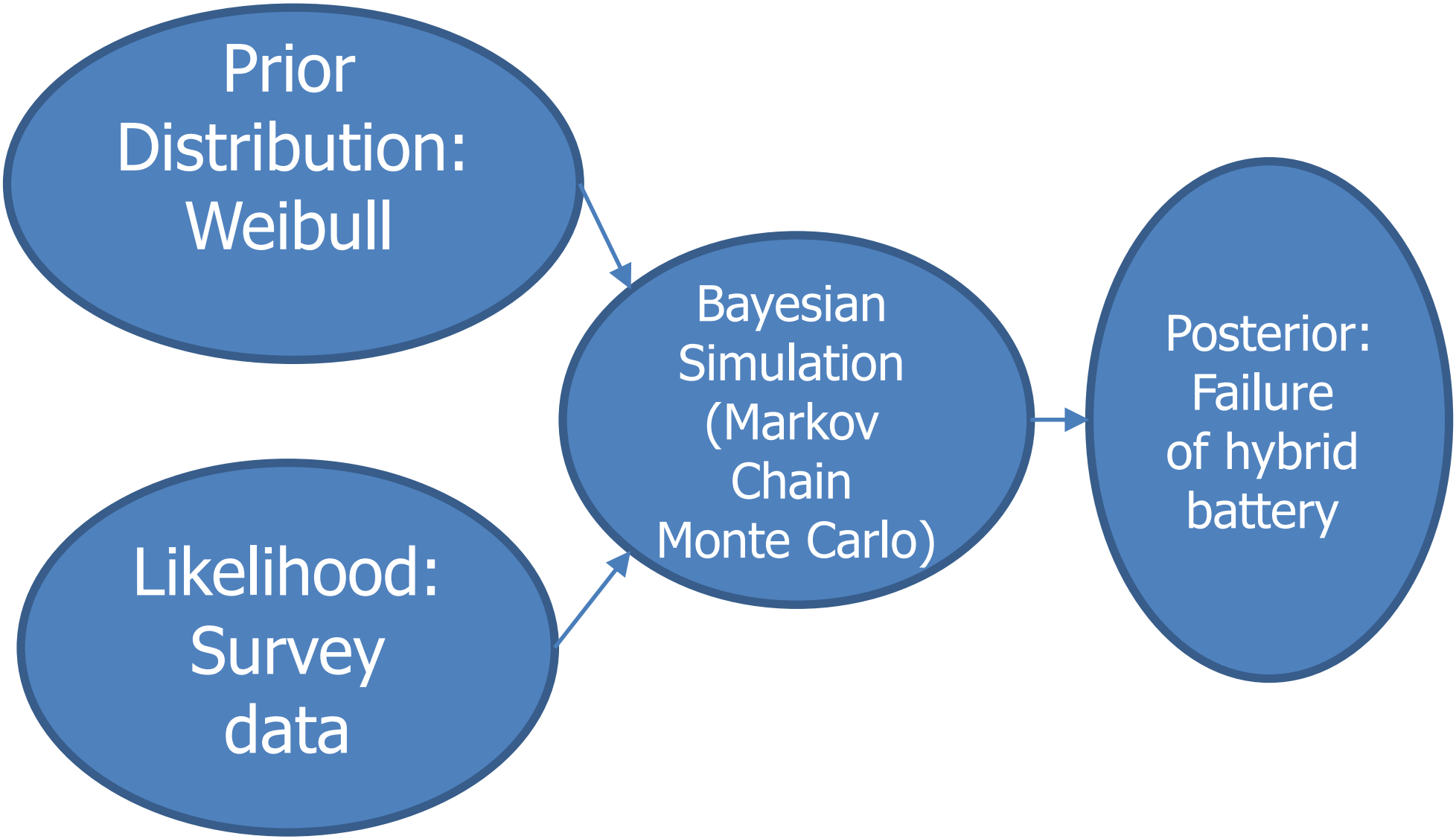
Use mean time to failure of a standard component to obtain the parameter of exponential distribution

Survey of Battery Performance

http://priuschat.com/threads/hybrid-battery-survey-gen2-prius-2004-2009.132362/

How is your Gen 2 Prius (2004-2009) Hybrid Battery Doing?		
Failed below 100,000 miles (7.8 years)	6 vote(s)	4.80%
Failed between 100,000 and 150,000 miles (7.8 years-11.7 years)	8 vote(s)	6.30%
Failed between 150,000 and 200,000 miles (11.7 years-15.6 years)	5 vote(s)	4.00%
Failed at over 200,000 miles (15.6 years)	1 vote(s)	0.80%
Has not failed below 100,000 miles (7.8 years)	42 vote(s)	33.30%
Has not failed between 100,000 and 150,000 miles (7.8 years-11.7 years)	37 vote(s)	29.40%
Has not failed between 150,000 and 200,000 miles (11.7 years-15.6 years)	19 vote(s)	15.10%
Has not failed at over 200,000 miles (15.6 years)	8 vote(s)	6.30%

Bayesian Analysis with Survey Data



Bayesian Analysis with Survey Data

Probability that the component fails within the time interval $[0, t]$ follows a Weibull distribution

$$P\,(T \leq t\,) = F(t|\beta,\lambda) = 1 - \exp\left(-\lambda t^{\beta}\right), \qquad t \geq 0$$

Failed below 100,000 miles (7.8 years)	6 vote(s)	4.80%

If a consumer reports that a component fails within a time interval $[t_1, t_2]$, likelihood of observing this result

$$P\,(t_1 \leq T \leq t_2\,) = F(t_2|\beta,\lambda) - F(t_1|\beta,\lambda)$$

Failed between 100,000 and 150,000 miles (7.8 years-11.7 years)	8 vote(s)	6.30%

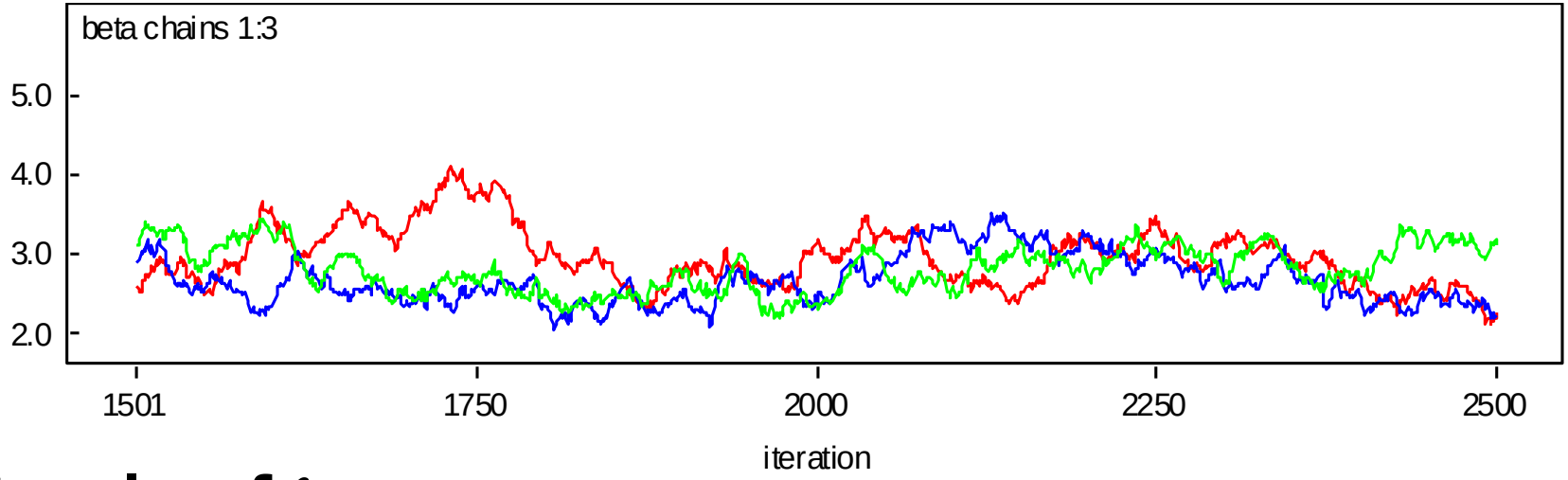
If a consumer reports that a component has not failed before t_3, the likelihood of observing this result

$$P\,(t_3 \leq T\,) = 1 - F(t_3|\beta,\lambda)$$

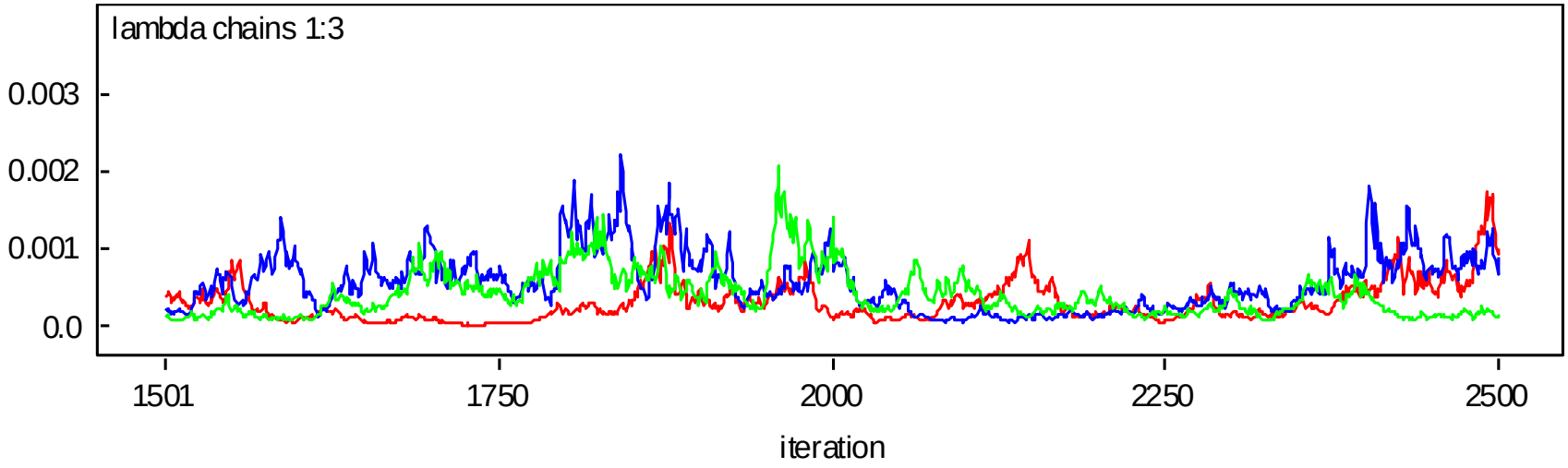
Has not failed below 100,000 miles (7.8 years)	42 vote(s)	33.30%

Gibbs Sampler Results for β and λ

Samples of β



Samples of λ



Histogram of Failure Time

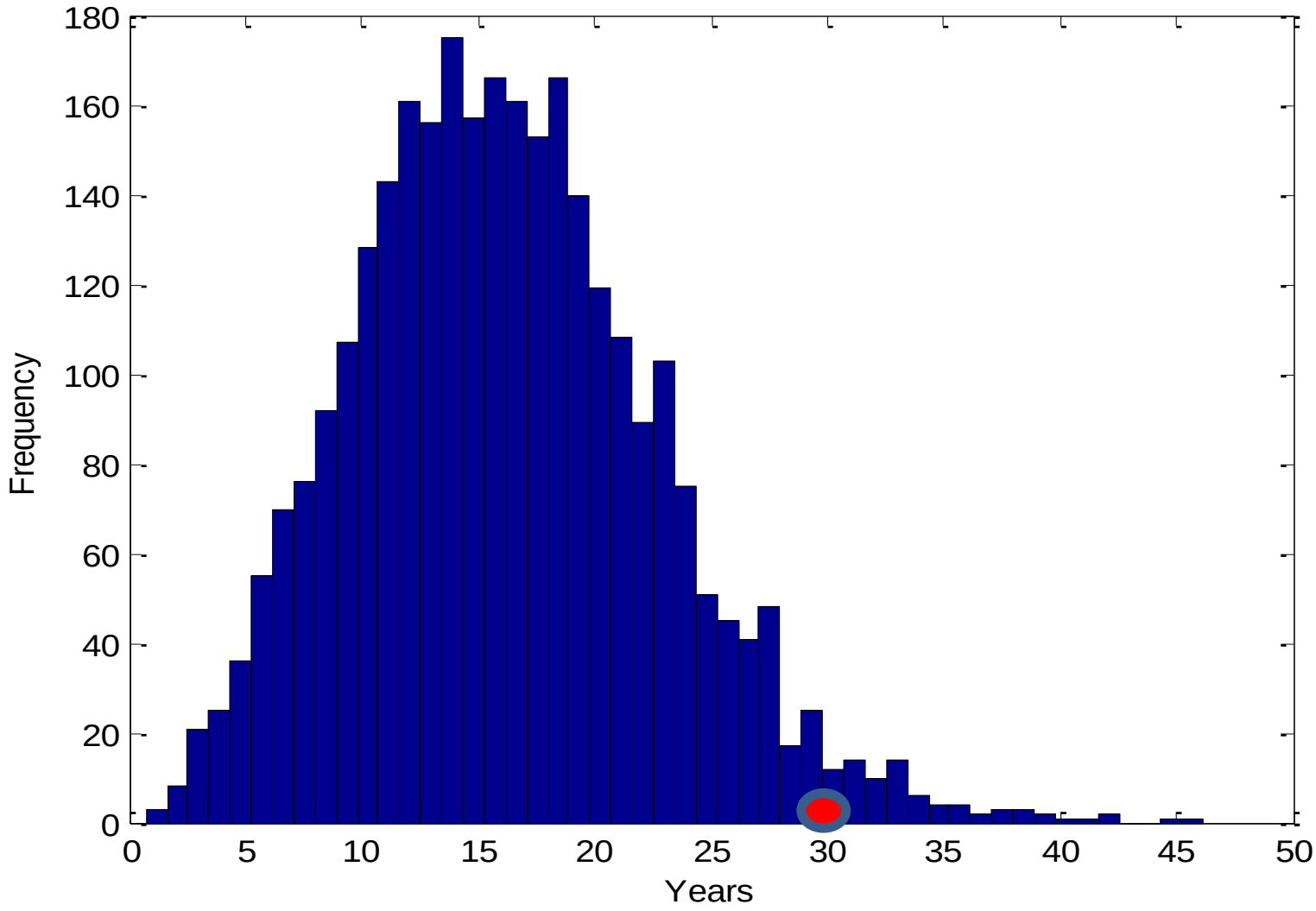


Fig 14. Histogram of failure time

Histogram of Failure Time

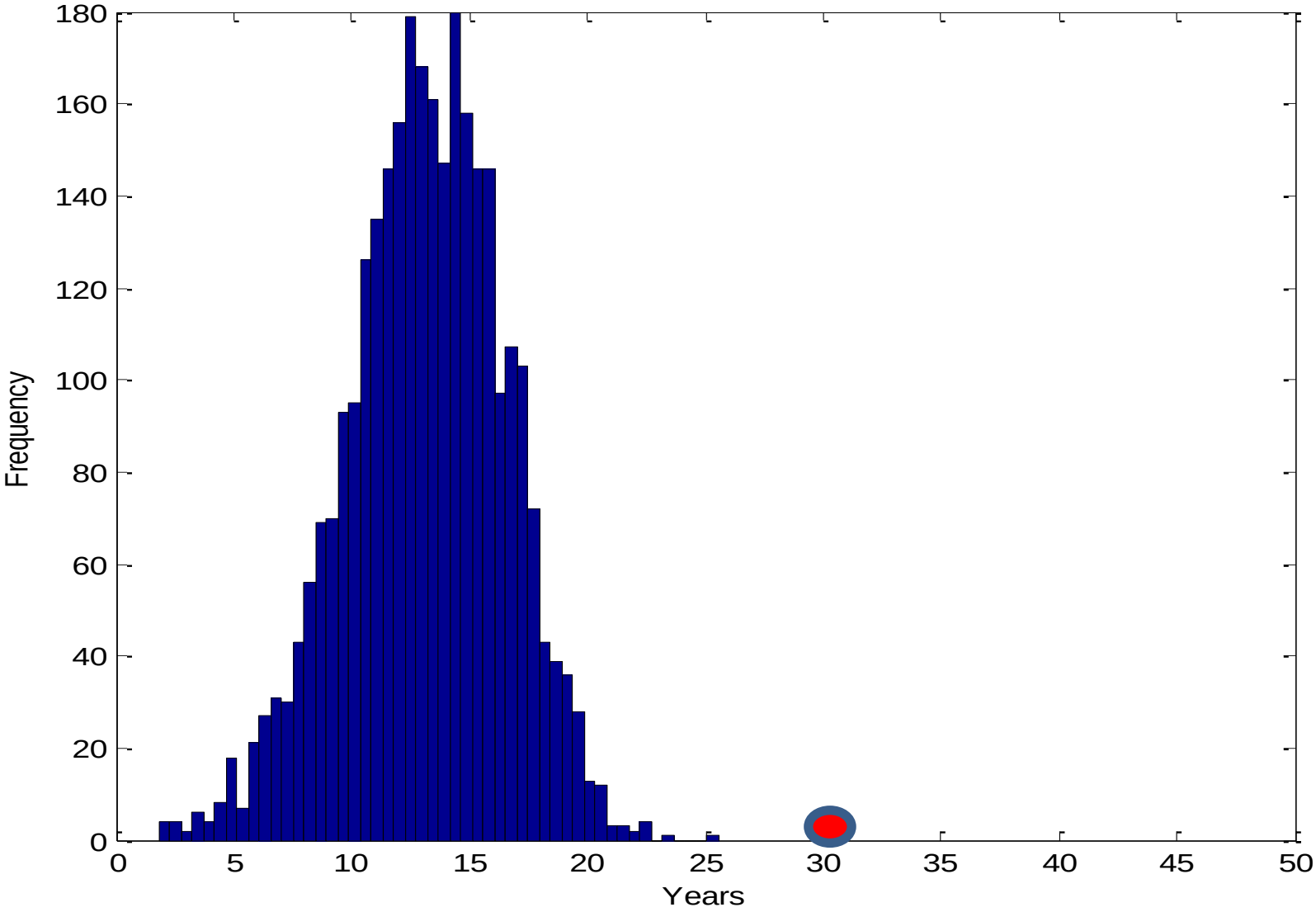


Fig 16. Histogram of failure times with upper limit of 250,000 miles

Probabilities of Components Failure

Component	MTTF	1/MTTF
1.HV Battery	13.50	0.07
2.Engine	9.40	0.11
3.MG1(vehicle electrical equipment)	8.36	0.12
4.MG2(vehicle electrical equipment)	8.36	0.12
4.PCU(vehicle power control unit)	2.68	0.37
6.Reduction Gear（Component of Mechanical System）	5.13	0.20
7.Planetary Gear（Component of Mechanical System）	5.13	0.20
8.Wheel（Component of Mechanical System）	5.13	0.20

MTTF of HV battery derived from Bayesian analysis

MTTF of other components derived from
Hu P, Zhou R, Zhen G. "Analysis on Reliability of Series Hybrid Electric Transit BUS[J]. " *Automobile Technology*, 2010.

MG1 and MG2 are vehicle electrical equipment

PCU is vehicle power control unit; Gear and wheel are the components of mechanical system

Probability of Operation Failure

P(1) = Probability of failure in first year

P(5) = Probability of failure in first 5 years

Scenario of Failure	P(1)	P(5)	P(10)	P(15)	P(20)
Start and low to mid-range speeds	0.59	0.99	1.00	1.00	1.00
Driving under normal conditions	0.50	0.97	1.00	1.00	1.00
Sudden acceleration	0.34	0.96	0.99	1.00	1.00
Deceleration or Braking	0.58	0.98	0.99	1.00	1.00
Battery recharging	0.55	0.98	0.99	1.00	1.00
Hybrid System totally fails	0.73	0.99	1.00	1.00	1.00

Probability of Operation Failure

Probabilities of operation failure due to the engine or HV battery :

Scenario of Failure	P(0)	P(1)	P(5)	P(10)	P(15)	P(20)
Start and low to mid-range speeds	0.00	0.00	0.01	0.18	0.70	0.99
Driving under normal conditions	0.00	0.10	0.41	0.65	0.80	0.88
Sudden acceleration	0.00	0.00	0.00	0.12	0.56	0.87
Deceleration or Braking	0.00	0.00	0.01	0.18	0.70	0.99
Battery recharging	0.00	0.10	0.42	0.72	0.94	1.00
Hybrid System totally fails	0.00	0.10	0.42	0.72	0.94	1.00

Probability of Operation Failure

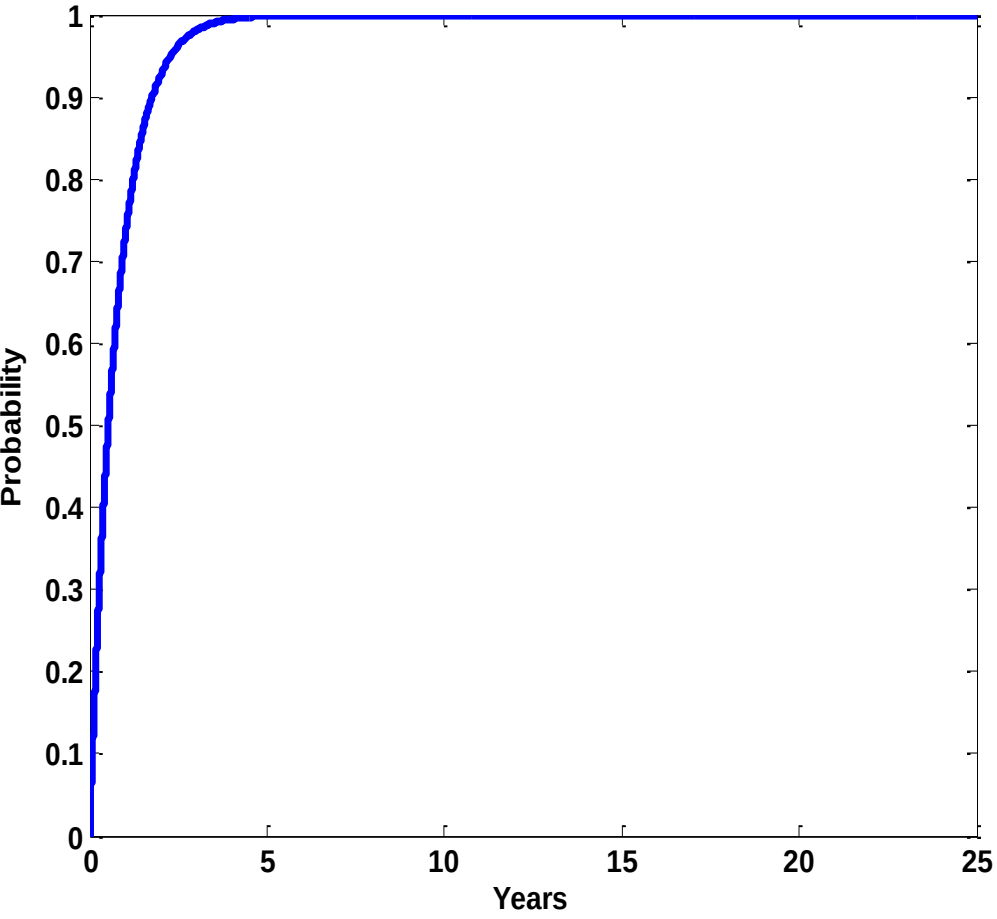


Figure 18. Probabilities of Failure of Entire Hybrid System

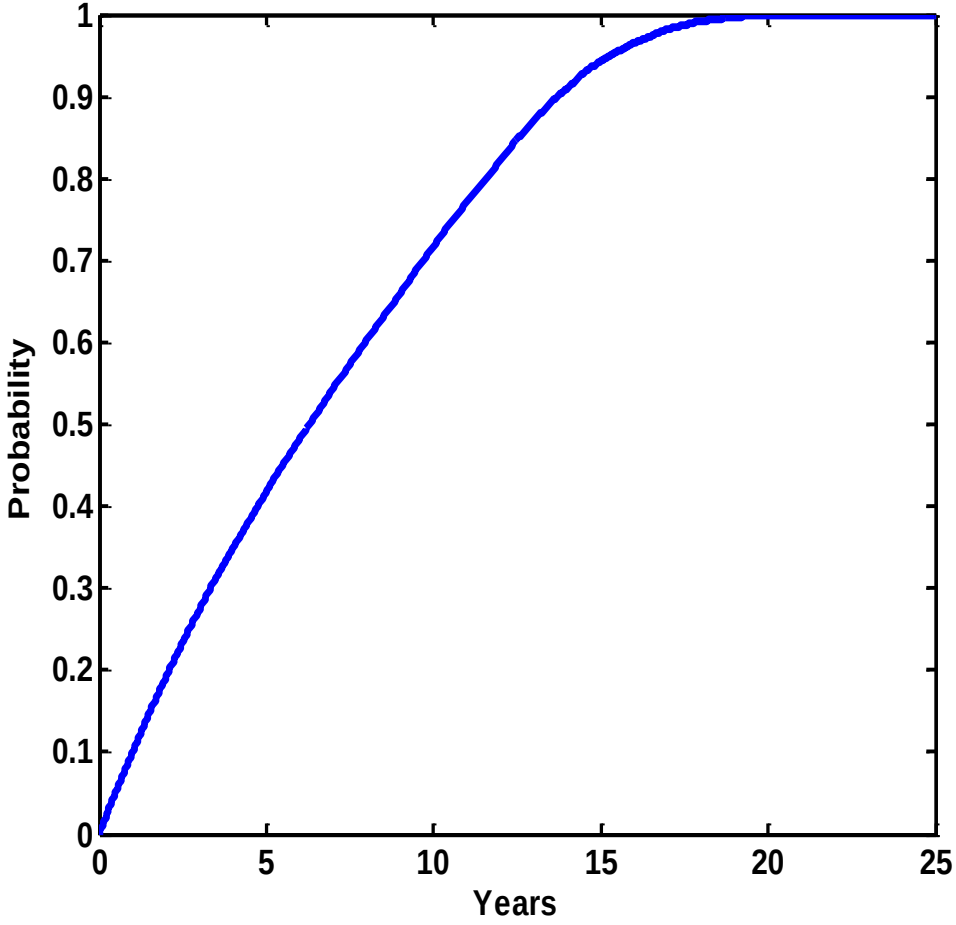


Figure 19. Probabilities of failure of entire hybrid system due to the HV battery or engine

Conclusions

1. The model presented provides a systematic framework for analyzing and estimating the reliability of a hybrid vehicle.

2. Bayesian analysis integrates survey data to assess the probability of failure for the HV battery—a unique method to measure the reliability.

3. Limitations:

- Several other components in a vehicle in addition to the eight components examined in this paper could also fail.
- Other factors not considered in this paper may also impact a vehicle's reliability.

Thank you!

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Questions

Please send mail to xlei@iastate.edu for paper

Bayes' rule: $p(\beta, \lambda|\mathbf{t}) = \dfrac{L(\mathbf{t}|\beta, \lambda)h(\beta)h(\lambda)}{p(\mathbf{t})}$

The Gibbs sampler is used to estimate the posterior distributions for β and λ.

1. Choose a set of initial values for the parameters β_0, λ_0
2. Generate $(\beta_1, \lambda_1|\beta_0, \lambda_0)$ by sampling:

   β_1 from $p(\beta|\lambda_0, \mathbf{t}))$

   λ_1 from $p(\lambda|\beta_1, \mathbf{t})$

3. Repeat step 2 n times to obtain chain $\{\beta_0, \lambda_0 ; \beta_1, \lambda_1; \ldots ; \beta_n, \lambda_n\}$.

Histogram of Failure Time

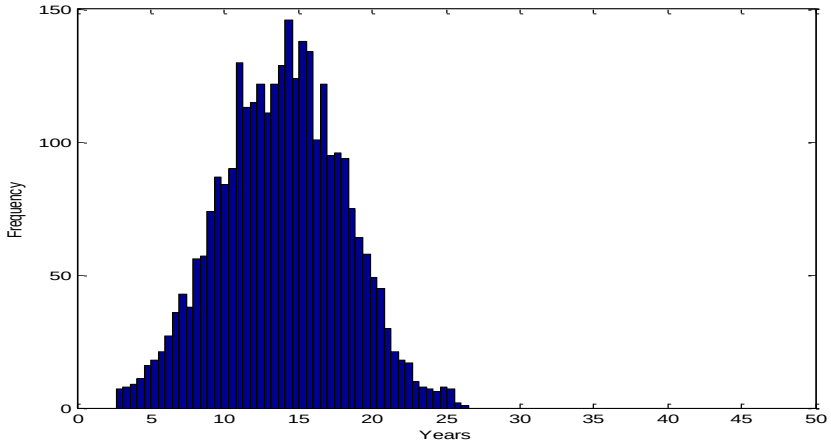

Fig 15. Histogram of failure times with upper limit of 300,000 miles

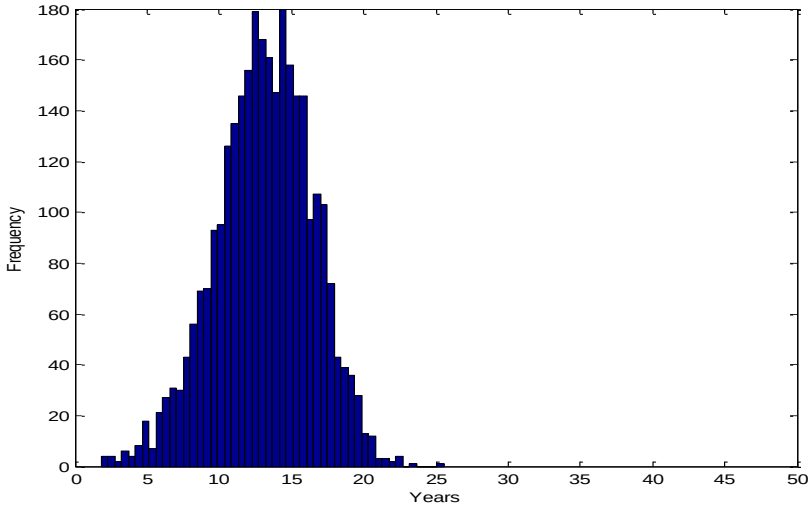

Fig 16. Histogram of failure times with upper limit of 250,000 miles

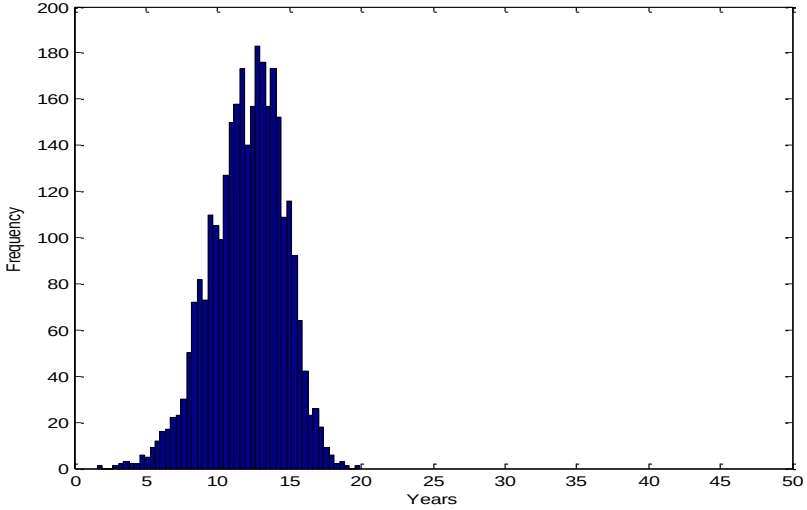

Fig 17. Histogram of failure times with upper limit of 200,000 miles

Probability that HV battery fail before a given time

Upper Bound	P(1 year)	P(5)	P(10)	P(15)	P(20)
No upper bound	0.00	0.02	0.18	0.45	0.73
300,000 miles	0.00	0.02	0.19	0.63	0.93
250,000 miles	0.00	0.01	0.18	0.70	0.99
201,000 miles	0.00	0.01	0.21	0.89	1.00