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A Tanks-in-Series Approach to Estimate Parameters for Lithium-ion Battery Models

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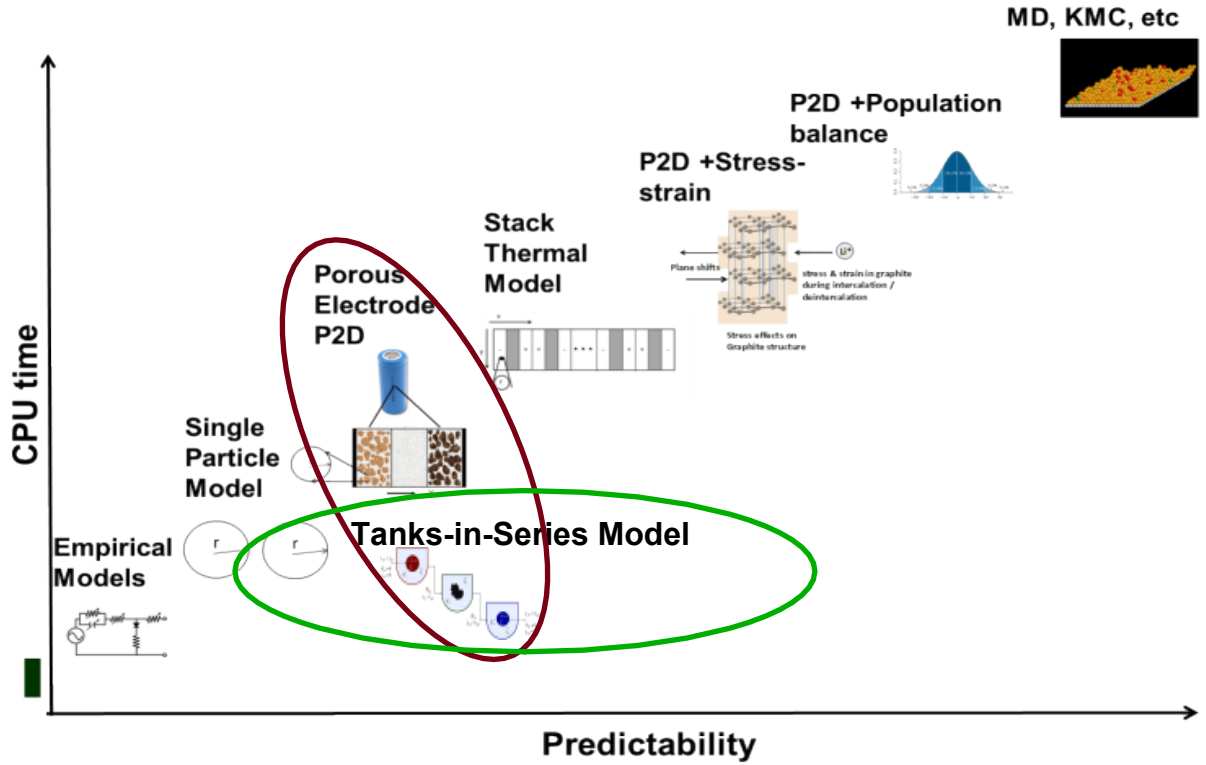
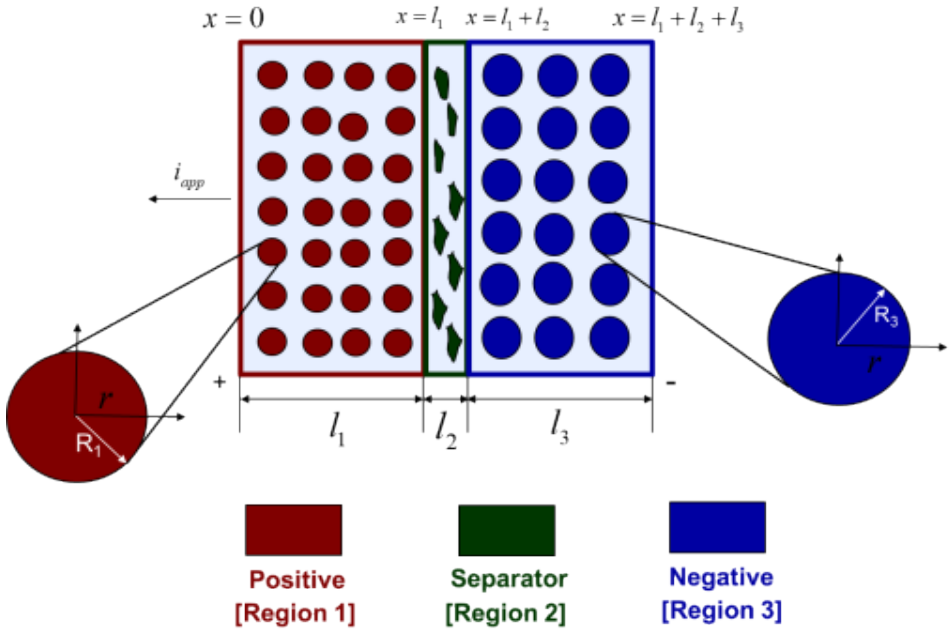
Speed Vs Accuracy

- Trade-off between CPU time vs. predictability.

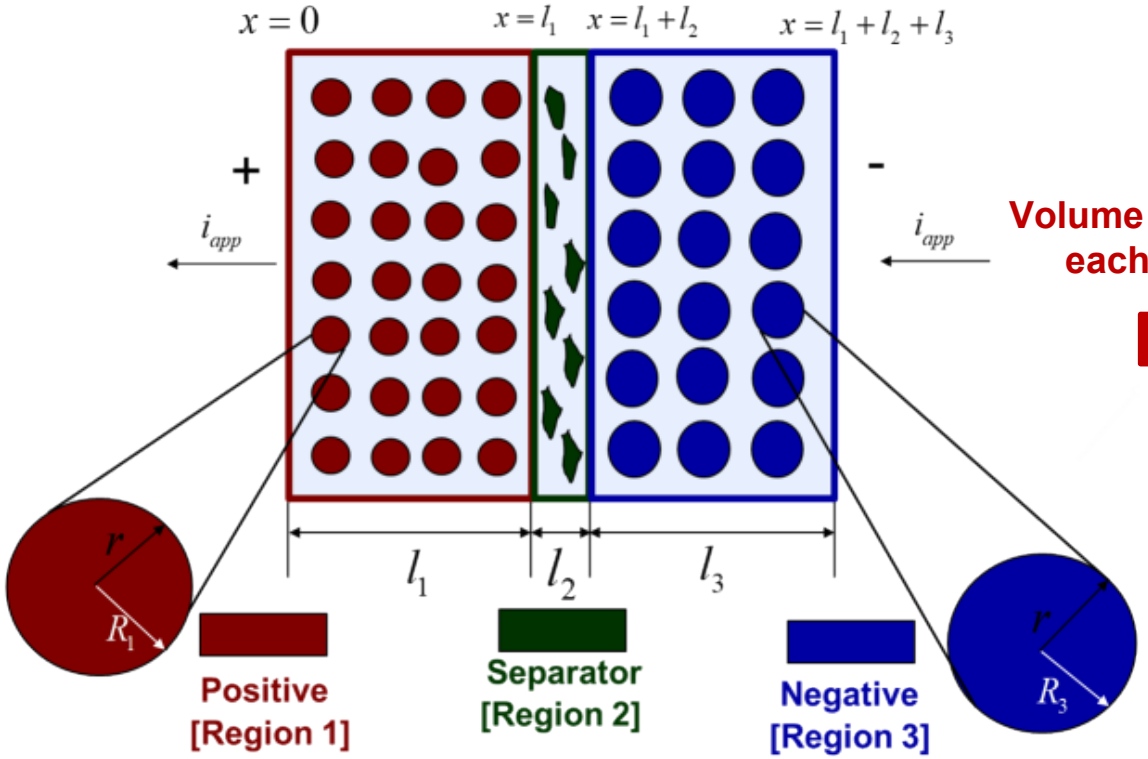




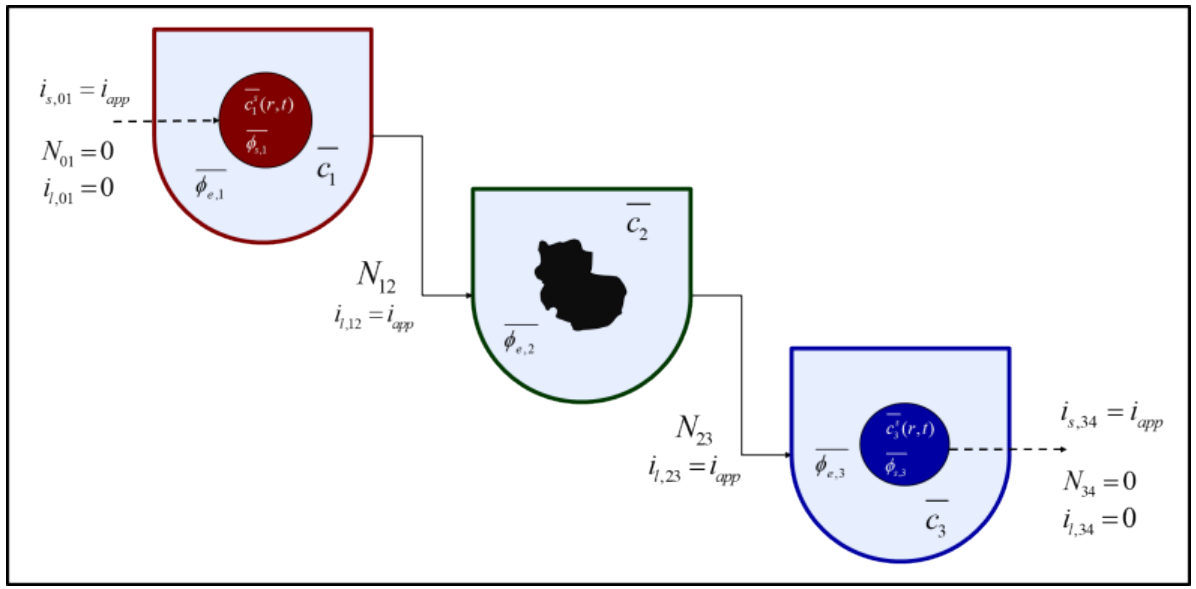
- P2D Model proposed by Newman & group
- Coupled Partial Differential Equations
- Accounts for
  - Electronic and Overall Charge
  - Electrolyte and Solid Phase Mass Conservation
  - Other Constitutive Equations

Adding more physics provides more fidelity and functionality for the Model, It also increases computational cost

Tanks-in-Series Battery Models



Volume averaging each region

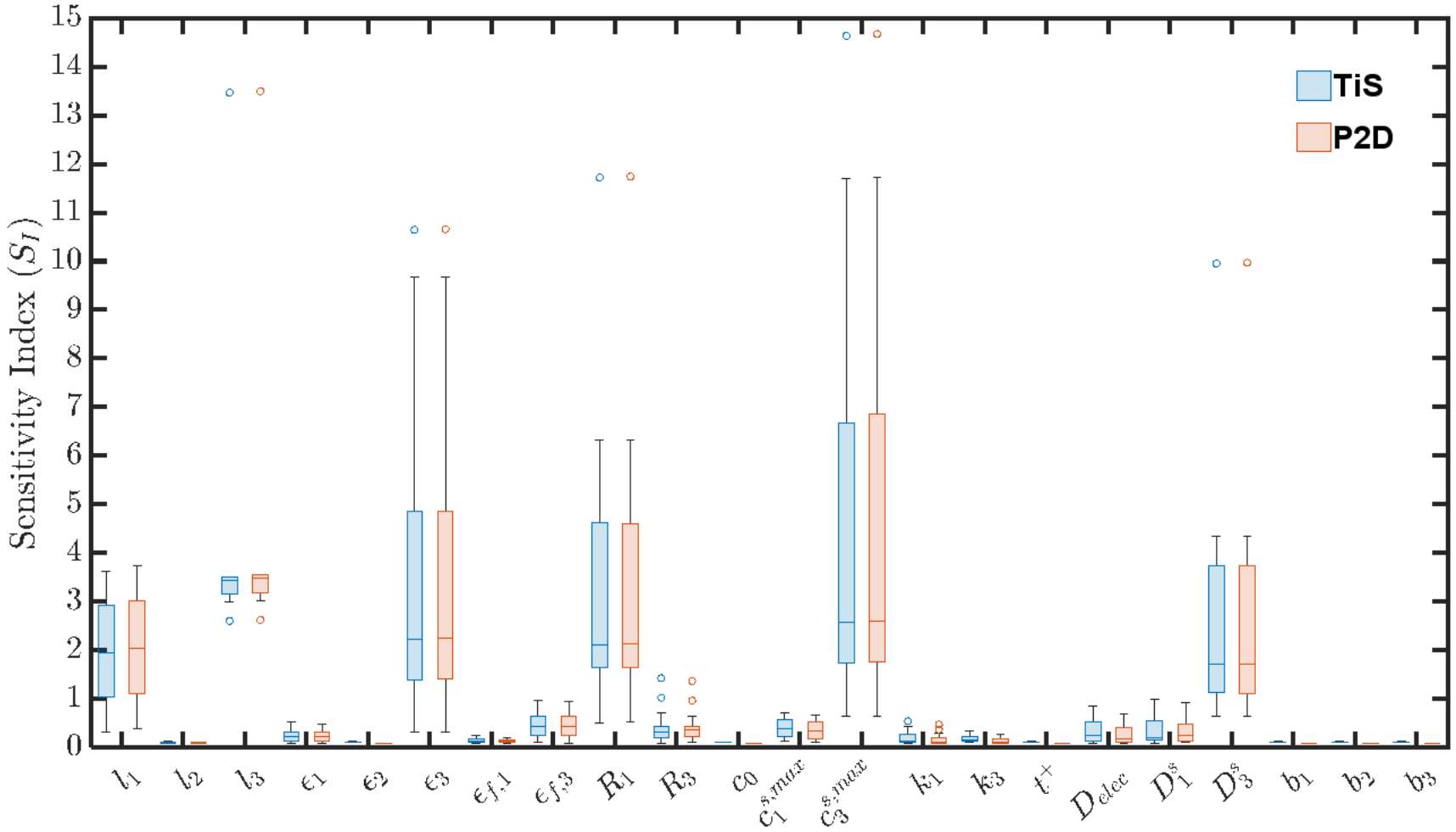


- P2D model > 1000 DAEs (complex)
- Computational time, C++: 5 seconds

- Tanks-in-Series model ~12 DAEs
- Computation time, C++: 0.018s
- <1% error observed as compared to existing physics-based battery models (SPM, P2D, etc.)

Ref: Subramaniam, A. et. al. (2020). JES, 167(1), 013534.

Parameter Sensitivity Analysis



- **P2D and TiS model are equally sensitive**
- **Enables to perform optimization and control studies with efficiently**

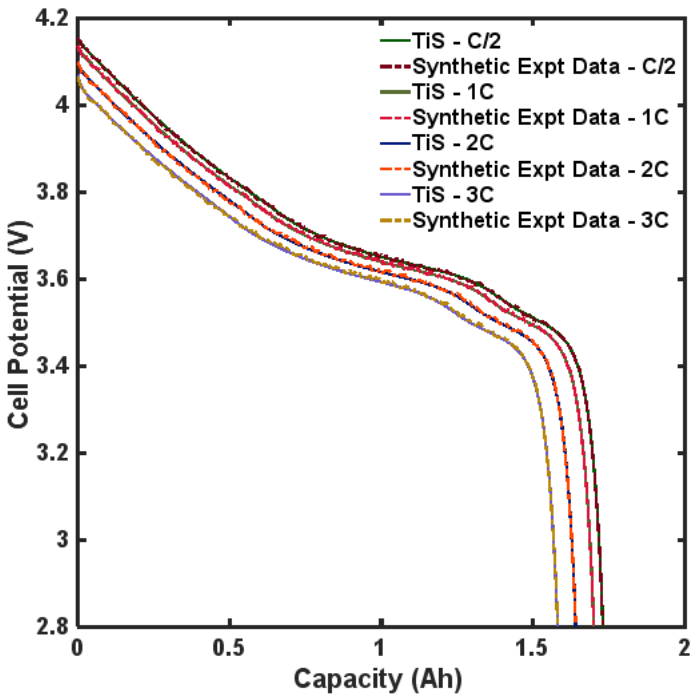
Optimization Formulation to Estimate Parameters

- **Optimization Formulation**

$$\min_{\theta_k} \sum_{i=1}^{n_{discharge}} \sqrt{\frac{\sum_{j=1}^{t(N_{pts,i})=t_f} \left[v_{expt,i}(t_j) - v_{model,i}(t_j;\theta_i) \right]^2}{N_{pts,i}}}$$

DAEs of Battery Model (P2D / TiS)

$$\theta_{k,low} \le \theta_k \le \theta_{k,high}, k = \{D_1^s, D_3^s\}$$



Comparison of optimization time required for P2D and TiS Model for two different optimization algorithms used from MATLAB

Optimizer	Genetic Algorithm (GA)		Sequential Quadratic Programming (SQP)	
Model	P2D	TiS	P2D	TiS
No. Function Evaluations	4855	4855	128	145
Optimization Time (s)	97200	1052.90	3060.38	32.17
RMSE (mV)	12.9	14.96	12.9	14.69
Optimal D_1^s m^2s^{-1}	2.011E-14	2.3282E-14	2.0114E-14	2.3276E-14
Optimal D_3^s m^2s^{-1}	1.4014E-14	1.4018E-14	1.4011E-14	1.4011E-14

Conclusion

- **TiS Model is 93-95 time faster in performing optimization**
- **Parameter sensitivity analysis was also performed to compare the fidelity of the TiS model.**

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Conference & Publications

Conferences

i. **S.Kolluri, P.Mittal, D.Gupta, A.Subramaniam, Y.Preger, K.Shah and V.R.Subramanian. Estimation of Grouped Parameters Using Tanks-in-Series Lithium-ion Battery Model, in: *239th Electro-Chemical Society (ECS) Meetings with the 18th International Meeting on Chemical Sensors*, Digital Meeting held on May 30th – June 3rd, 2021.**

ii. **S.Kolluri, A.Subramaniam, P.Mittal, Y.Preger, K.Shah and V.R.Subramaniam. Parameter Estimation of Lithium-ion Battery Models Using a Novel Tanks-in-Series Approach, in: *Pacific Rim Meeting on Electrochemical and Solid-State Science (PRiME 2020)*, Digital Meeting held on October 4th – 9th, 2020.**

Manuscript Under Preparation

i. **S.Kolluri, P.Mittal, A.Subramaniam, Y.Preger, V.Ramadesigan and V.R.Subramanian. A Tanks-in-Series Approach to Estimate Parameters for Lithium-ion Battery Models *(Will be soon submitted)***