Collaborative Acute Toxicity Modeling Suite (CATMoS)

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Disclaimer: ILS staff provide technical support for NICEATM, but do not represent NIEHS, NTP, or the official positions of any federal agency.

(the author declares no conflict of interest)
Overview

• Project scope: acute oral toxicity
  – Regulatory use of these data
  – Endpoints selected for predictive modeling
  – Compiling inventory of rat acute oral LD50
  – Establishing training, evaluation, and prediction sets
  – Evaluation of submitted models

• International contributors

• Generation of consensus predictions

• Current status and public release
Toxicity prediction

Too many chemicals to test with standard animal-based methods
– Cost, time, animal welfare

Alternative

• Organic pollutants with exposure potential accumulate in body tissues
  ➢ Cause toxic effects to wild life and humans
• Existence of gaps in the experimental data for environmental endpoints
  ➢ Need to fill the data gaps and bridge the lack of knowledge
• Regulatory requirements:
  ➢ Reduce animal testing, time and costs
  ➢ Methodology: use of QSAR/QSPR to predict the endpoints of interest.
ICCVAM Acute Toxicity Workgroup

- Identifies federal agency requirements, needs, and decision contexts for using acute systemic toxicity data
Agency-Based Modeling Endpoint Selection

**Binary Models**
- Highly toxic (≤50 mg/kg)
- Toxic (>50-5000 mg/kg)
- Nontoxic (>2000 mg/kg)

**Continuous Model**
- Point estimates of LD50 values

**Categorical Models**
- **EPA Categories**
  - I (≤ 50 mg/kg)
  - II (>50 ≤ 500 mg/kg)
  - III (>500 ≤ 5000 mg/kg)
  - IV (>5000 mg/kg)
- **GHS Categories**
  - I (≤ 5 mg/kg)
  - II (>5 ≤ 50 mg/kg)
  - III (>50 ≤ 300 mg/kg)
  - IV (>300 ≤ 2000 mg/kg)
  - NC (> 2000 mg/kg)
Available data for modeling

Rat oral LD50s:
16,297 chemicals total
34,508 LD50 values

15,688 chemicals total
21,200 LD50 values

QSAR-ready standardization
Desalted, stereochemistry stripped,
tautomers and nitro groups standardized,
valence corrected, structures neutralized

11992 chemicals with accurate structures

• Very toxic endpoint: 11886 entries (binary, 0/1)
• Non-toxic endpoint: 11871 entries (binary, 0/1)
• EPA endpoint: 11755 entries (categorical, 4 categories)
• GHS endpoint: 11845 entries (categorical, 5 categories)
• LD50 endpoint: 8908 entries (continuous values)
Aim of the workflow:
- Combine different procedures and ideas
- Minimize the differences between the structures used for prediction
- Produce a flexible free and open source workflow to be shared

Wedebye et al. Danish EPA Environmental Project No. 1503, 2013
Mansouri et al. (http://ehp.niehs.nih.gov/15-10267/)
Establishing Modeling Dataset

• **Training and evaluation sets:**

  • 11,992 chemicals from the final inventory of chemicals with QSAR-ready structures having rat oral acute toxicity data were split into training and test sets:
    • 75% training set: 8,994 chemicals
    • 25% evaluation set: 2,998 chemicals

  • All endpoints training data included in same structure file
  • Similar distributions and variability for values and categories
  • Similar distribution of chemical structures sources
Establishing Modeling Dataset

• Prediction set:

**Included lists of regulatory interest:**

• ToxCast/Tox21
• EDSP
• TSCA
• Substances on the market (EPA Dashboard list)

After QSAR-ready standardization:

48137 structures to be predicted (including the evaluation set)
ChemMaps landscape of CATMoS chemicals

http://www.chemmaps.com/chemmaps/DSSToxMap3D/
Consortium:

- **35 Participants/Groups** from around the globe representing academia, industry, and government contributed

(https://batchgeo.com/map/d06c5d497ed8f76ecfee500c2b0e1dfa)
Submitted Models

- Non-toxic: 33 models
- Very Toxic: 32 models
- GHS categories: 23 models
- EPA categories: 26 models
- LD50: 25 models

Total: 139 models
Evaluation procedure

**Qualitative evaluation:**
- Documentation
- Defined endpoint
- Unambiguous algorithm
- Availability of code
- Applicability domain definition
- Availability of data used for modeling
- Mechanistic interpretation

**Quantitative evaluation:**
- Goodness of fit: training statistics
- Evaluation set predictivity: statistics on the evaluation set
- Robustness: balance between (Goodness of fit) & (Test set predictivity)

\[
S = 0.3 \times \text{(Goodness of fit)} + 0.45 \times \text{(Test set predictivity)} + 0.25 \times \text{(Robustness)}
\]

**Categorical models (binary and multi-class):**

Goodness of fit = 0.7 \times (BA_{Tr}) + 0.3 \times (1 - |Sn_{Tr} - Sp_{Tr}|)

Test set predictivity = 0.7 \times (BA_{Tst}) + 0.3 \times (1 - |Sn_{Tst} - Sp_{Tst}|)

Robustness = 1 - |BA_{Tr} - BA_{Tst}|

**Continuous models:**

Goodness of fit = R^2_{Tr}

Test set predictivity = R^2_{Tst}

Robustness = 1 - |R^2_{Tr} - R^2_{Tst}|
Coverage and concordance of the models

- Histogram showing the distribution of prediction set chemicals for different models (VT, NT, EPA, GHS, LD50).
- Bar chart illustrating the predictions concordance for various model predictions.
CATMoS consensus modeling

Steps of combining the single models into consensus

**Initial models & predictions**
- VT (32 models)
- NT (33 models)
- GHS (23 models)
- EPA (26 models)
- LD50 (25 models)

**Combining models**

**Step 1**
- Weighted average/majority rule

**Independent consensus models/predictions**
- VT
- NT
- GHS
- EPA
- LD50

**Step 2**
- Weight of Evidence approach (WoE)
- Majority rule

**Consistent consensus models/predictions**
- VT
- NT
- GHS
- EPA
- LD50

A consensus model per endpoint (~20-~30 models)

Consensus representing all ~140 models
WoE approach to combine the 5 endpoints

<table>
<thead>
<tr>
<th>molX</th>
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<th>50</th>
<th>300</th>
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WoE approach to combine the 5 endpoints

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Variability range (log units) for LD50

Model Prediction

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<th>300</th>
<th>500</th>
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### WoE approach to combine the 5 endpoints

**Original: independent calls**

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**WoE: consistent calls**

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**Model Prediction**

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<td>4</td>
<td>3</td>
<td>1</td>
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</tr>
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</table>

**How to adjust quantitative LD50?**

Avg of Lower CI and upper bin threshold

\[
\frac{(160 + 300)}{2} = \frac{460}{2} = 230 \text{mg/kg}
\]
The consensus predictions perform just as well as replicate *in vivo* data do at predicting oral acute toxicity outcome.
Extended CATMoS predictions

Weighted read-across

\[ d_1 = 0 \]
\[ \text{Pred}_i = N_i \]

\[ d_1 \neq 0 \]
\[ w_i = f(d_i) \]
\[ \text{Pred}_i = f(w_i, N_i) \]

- New chemical to be predicted
- Nearest neighbors (\( N_i \))

\[ d_i \]: Euclidean distance based on the selected descriptors for each endpoint

Automated, similarity-endpoint dependent read-across: weighted kNN
Generation of Consensus Predictions

- Models passing qualitative evaluation (requirement for transparency; description of approach was sufficient)

- Integrating only *in-domain* predictions across chemicals in the prediction set (48,137 chemicals) for each model, respectively
  - Categorical models: weighted majority rule
  - Continuous model: weighted average
Collaboration with ATWG partners and ICCVAM agencies

<table>
<thead>
<tr>
<th>Agency</th>
<th>No. Substances</th>
<th>Agency</th>
<th>No. Substances</th>
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<tr>
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<tr>
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<tr>
<td>DOT</td>
<td>3671</td>
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</tr>
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Evaluate and optimize CATMoS predictions based on lists of interest
Running CATMoS Consensus models

OPERA Standalone application

- Free, open-source & open-data
- Single chemical and batch mode
- Multiple platforms (Windows and Linux)
- Embeddable libraries (java, C, C++, Python)

https://github.com/NIEHS/OPERA

**OPERA2**

**OPERA 1.5**

**Physchem & Environmental fate:**

<table>
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<tr>
<th>Model</th>
<th>Property</th>
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<td>AOH</td>
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<tr>
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<td>Bioconcentration Factor</td>
</tr>
<tr>
<td>BioHL</td>
<td>Biodegradation Half-life</td>
</tr>
<tr>
<td>RB</td>
<td>Ready Biodegradability</td>
</tr>
<tr>
<td>BP</td>
<td>Boiling Point</td>
</tr>
<tr>
<td>HL</td>
<td>Henry's Law Constant</td>
</tr>
<tr>
<td>KM</td>
<td>Fish Biotransformation Half-life</td>
</tr>
<tr>
<td>KOA</td>
<td>Octanol/Air Partition Coefficient</td>
</tr>
<tr>
<td>LogP</td>
<td>Octanol-water Partition Coefficient</td>
</tr>
<tr>
<td>MP</td>
<td>Melting Point</td>
</tr>
<tr>
<td>KOC</td>
<td>Soil Adsorption Coefficient</td>
</tr>
<tr>
<td>VP</td>
<td>Vapor Pressure</td>
</tr>
<tr>
<td>WS</td>
<td>Water solubility</td>
</tr>
<tr>
<td>RT</td>
<td>HPLC retention time</td>
</tr>
</tbody>
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**New in OPERA2:**

- **Physchem properties:**
  - General structural properties
  - pKa
  - Log D

- **ADME properties**
  - Plasma fraction unbound (FuB)
  - Intrinsic clearance (Clint)

- **Toxicity endpoints**
  - ER activity (CERAPP)
    [https://ehp.niehs.nih.gov/15-10267/](https://ehp.niehs.nih.gov/15-10267/)
  - AR activity (CoMPARA)
    [https://doi.org/10.13140/RG.2.2.19612.80009](https://doi.org/10.13140/RG.2.2.19612.80009)
  - Acute toxicity (CATMoS)
    [https://doi.org/10.1016/j.comtox.2018.08.002](https://doi.org/10.1016/j.comtox.2018.08.002)
CATMoS prediction examples

1,4-Dioxane
123-91-1 | DTXSID4020533
Molecular Formula: C_4H_8O_2
Average Mass: 88.106 g/mol
LD50: 4200 mg/kg
log10 LD50 = 3.62

https://comptox.epa.gov/dashboard/dsstoxdb/results?search=DTXSID4020533

Vitamin D3
67-97-0 | DTXSID6026294
Molecular Formula: C_{27}H_{44}O
Average Mass: 384.648 g/mol
LD50: 42 mg/kg
log10 LD50 = 1.62

https://comptox.epa.gov/dashboard/dsstoxdb/results?search=DTXSID6026294

CATMoS predictions:

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<th>MoleculeID</th>
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<th>CATMoS_GHS_pred</th>
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</table>
Soon on NTP/ICE and EPA CompTox dashboard

https://ntp.niehs.nih.gov/

https://comptox.epa.gov/dashboard
The “3C” Concept at Work!

- Success of the project was due in great part to the use of the 3C concept as well as up-front and continuous engagement of regulators in the process.

https://ntp.niehs.nih.gov/go/natl-strategy
Thank you!

- ICCVAM Acute Toxicity Workgroup
- EPA/NCCT
  - Grace Patlewicz
  - Jeremy Fitzpatrick
- ILS/NICEATM
  - Agnes Karmaus
  - Dave Allen
  - Shannon Bell
  - Patricia Ceger
  - Judy Strickland
  - Amber Daniel
- NTP/NICEATM
  - Nicole Kleinstreuer
  - Warren Casey

Feedback welcome: Kamel Mansouri (kmansouri@ils-inc.com)

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