Calibration Model 01: Bayesovská kalibrace (Bayes Calibration)

Počet kalibrovaných parametrů: 3

Kalibrační framework

- Zarovnat časové osy
- Definovat dynamický model
- Zavést prior na parametry
- Zavést prior na šum
- Přidat modelovou diskrepanci
- MCMC sampling
- Posterior predictive kontrola

In [1]:

```
# Instalace potřebných knihoven
#%pip install pandas
#%pip install numpy
#%pip install seaborn matplotlib
#%pip install pymc
#%pip install arviz
#%pip install ipywidgets
#%pip install jupyterlab_widgets
#%pip install pytensor
#%pip install ipywidgets jupyterlab_widgets
```

In [2]:

```
# Import potřebných knihoven
import pandas as pd
import numpy as np

import pymc as pm
import arviz as az
import pytensor.tensor as pt

import seaborn as sns
import matplotlib.pyplot as plt
```

Vstupní data

In [3]:

```
### Načtení časosběru

# Soubor je načten a přiřazen do proměnné ‚df‘
other_path = '../../data/02_DetermModel/model_data_real.csv'
df = pd.read_csv(other_path, header=0)
df = df[['id', 'x', 'y', 'z', 'dist', 'time', 'total_time']]
df
```

Out[3]:

	id	x	y	z	dist	time	total_time
0	150	1315	220	1000	3443	29	29
1	75	220	1190	500	3590	33	33
2	239	220	940	2000	4387	35	41
3	199	1315	220	1500	3636	36	36
4	51	3690	220	250	5767	50	50
...	...	...	...	...	...	...	...
156	83	220	3190	500	1970	29	29
157	26	1815	220	0	3943	45	45
158	190	220	690	1500	4351	33	33
159	234	220	3815	1750	2990	27	27
160	195	220	3940	1500	2981	35	35

161 rows × 7 columns

Vhodné parametry pro kalibraci

Parametr	Kalibrovat	Důvod
speed_max_load	Ano	reálná rychlost ≠ nominální
speed_max_unload	Ano	často vyšší variabilita
accel	Ano	výrazně ovlivňuje krátké cykly
pevné časy	Ne (slabý prior)	většinou měřené přesně

In [4]:

```
dist = df["dist"].values
time_real = df["time"].values
```

Fyzikální model (vektorový)

In [5]:

```
def move_time(dist, v, a):

    t_acc = v / a
    d_acc = 0.5 * a * t_acc**2
    d_crit = 2 * d_acc

    # trojúhelníkový profil
    triangular = 2 * pt.sqrt(dist / a)

    # trapezoidální profil
    trapezoidal = 2 * t_acc + (dist - d_crit) / v

    return pt.switch(dist < d_crit,
                     triangular,
                     trapezoidal)
```

Kompletní model

In [6]:

```
with pm.Model() as model:

    # ------------------------
    # Priory (fyzikálně omezené)
    # ------------------------

    v_load = pm.TruncatedNormal("v_load",
                                mu=0.5,
                                sigma=0.2,
                                lower=0.1)

    v_unload = pm.TruncatedNormal("v_unload",
                                  mu=1.0,
                                  sigma=0.3,
                                  lower=0.2)

    accel = pm.TruncatedNormal("accel",
                               mu=1.0,
                               sigma=0.3,
                               lower=0.2)

    sigma = pm.HalfNormal("sigma", 0.2)

    # ------------------------
    # Fixní část cyklu
    # ------------------------

    time_refer_2_refer = 20   # s, průměrná doba pohybu z referenčního bodu k referenčnímu boc
    time_mounting = 3         # s, doba manipulaci v cílové poloze (umístění prvku)

    T_fix = time_refer_2_refer + time_mounting
    # ------------------------
    # Pohyb
    # ------------------------

    T_load = move_time(dist/1000, v_load, accel)
    T_unload = move_time(dist/1000, v_unload, accel)

    mu = T_fix + T_load + T_unload

    # ------------------------
    # Likelihood
    # ------------------------

    y = pm.Normal("y",
                  mu=mu,
                  sigma=sigma,
                  observed=time_real)

    trace = pm.sample(3000,
                      tune=2000,
                      target_accept=0.95)
```

```
Initializing NUTS using jitter+adapt_diag...
Multiprocess sampling (4 chains in 4 jobs)
NUTS: [v_load, v_unload, accel, sigma]
```

```
Output()
```

```
Sampling 4 chains for 2_000 tune and 3_000 draw iterations (8_000 + 12_000 draws total) took 1
1 seconds.
```

Diagnostika

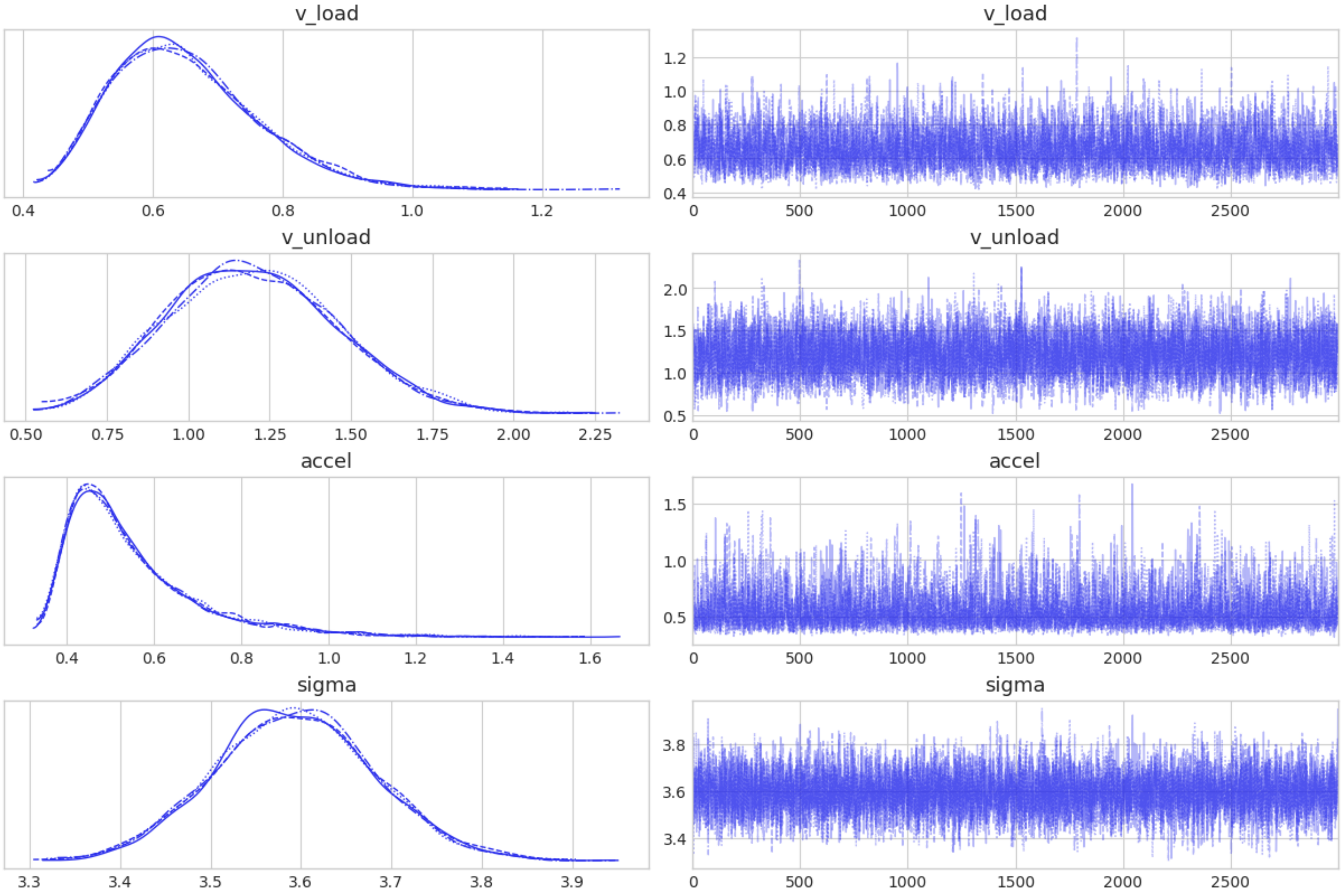
In [7]:
```
az.summary(trace)

az.style.use("arviz-whitegrid")

plt.rcParams.update({
    "figure.figsize": (12, 8),
    "font.size": 12,
    "axes.titlesize": 13,
    "axes.labelsize": 11,
    "legend.fontsize": 10,
    "xtick.labelsize": 10,
    "ytick.labelsize": 10,
    "lines.linewidth": 1.0,
})

az.plot_trace(trace)
```

Out[7]:
```
array([[<Axes: title={'center': 'v_load'}>,
        <Axes: title={'center': 'v_load'}>],
       [<Axes: title={'center': 'v_unload'}>,
        <Axes: title={'center': 'v_unload'}>],
       [<Axes: title={'center': 'accel'}>,
        <Axes: title={'center': 'accel'}>],
       [<Axes: title={'center': 'sigma'}>,
        <Axes: title={'center': 'sigma'}>]], dtype=object)
```



Posterior predictive kontrola

In [8]:
```
with model:
    trace.extend(
        pm.sample_posterior_predictive(trace)
    )
```

```
Sampling: [y]
Output()
```

In [9]:

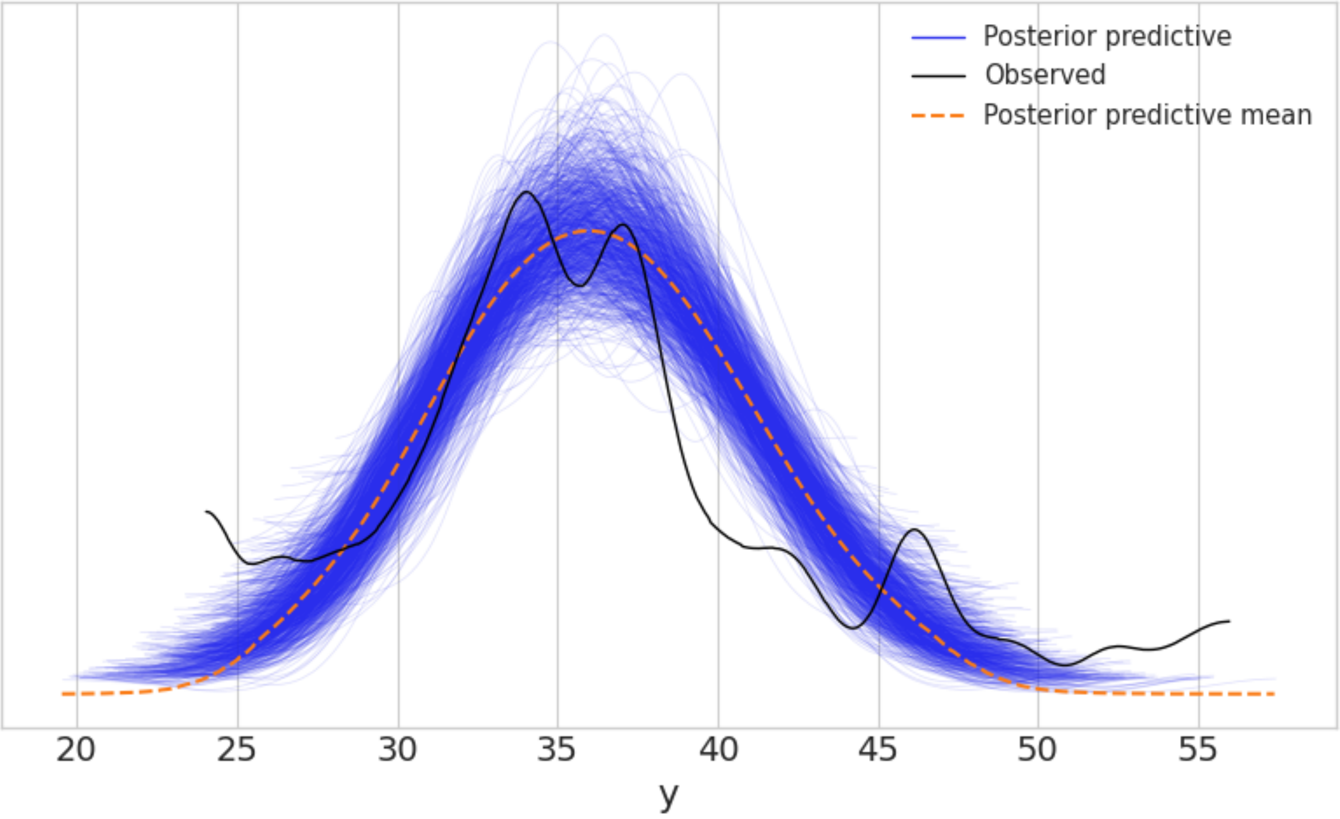
```
az.style.use("arviz-whitegrid")

fig, ax = plt.subplots(figsize=(8,5))

az.plot_ppc(
    trace,
    num_pp_samples=1000,      # don't plot all draws!
    kind="kde",
    mean=True,
    observed=True,
    alpha=0.15,
    ax=ax
)

plt.tight_layout()
```

```
C:\Users\usman\AppData\Local\Temp\ipykernel_26088\3615469113.py:15: UserWarning: The figure la
yout has changed to tight
  plt.tight_layout()
```



Souhrnná statistika posteriorní prediktivní distribuce modelu

In [10]:

```
summary_df = az.summary(trace, group="posterior_predictive")
summary_df
```

Out[10]:

	mean	sd	hdi_3%	hdi_97%	mcse_mean	mcse_sd	ess_bulk	ess_tail	r_hat
y[0]	35.076	3.648	27.950	41.694	0.034	0.024	11780.0	11754.0	1.0
y[1]	35.395	3.623	28.546	42.153	0.033	0.023	11754.0	11610.0	1.0
y[2]	37.378	3.629	30.475	44.050	0.033	0.024	11829.0	11373.0	1.0
y[3]	35.472	3.642	28.580	42.283	0.033	0.024	11944.0	11685.0	1.0
y[4]	40.741	3.655	34.193	47.982	0.033	0.024	12393.0	11902.0	1.0
...	...	...	...	...	...	...	...	...	...
y[156]	31.350	3.587	24.531	38.050	0.033	0.023	11538.0	11687.0	1.0
y[157]	36.211	3.589	29.611	43.083	0.033	0.023	11917.0	11931.0	1.0
y[158]	37.231	3.594	30.660	44.089	0.033	0.023	11562.0	11187.0	1.0
y[159]	33.884	3.649	27.332	40.911	0.033	0.024	12204.0	11572.0	1.0
y[160]	33.910	3.638	27.065	40.661	0.033	0.023	12163.0	11596.0	1.0

161 rows × 9 columns

Export datové sady do formátu netCDF a CSV

https://www.unidata.ucar.edu/software/netcdf

In [11]:

```
summary_df.to_csv("../../data/05_Calibration/posterior_predictive_summary_three.csv", index=Fa
```

In [12]:

```
az.to_netcdf(trace, "../../data/05_Calibration/posterior_trace_three.nc")
```

Out[12]:

```
'../../data/05_Calibration/posterior_trace_three.nc'
```

In [13]:

```
df_posterior = az.extract(trace, group="posterior").to_dataframe()
df_posterior.to_csv("../../data/05_Calibration/posterior_three.csv", index=False)
```

Autor / Organizace / Datum

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Přehled změn

Datum (YYYY-MM-DD)	Verze	Autor změny	Popis změny
2026-01-31	1.1	Vjačeslav Usmanov	added CM_01_BayesCalibration.ipynb
2026-02-18	1.2	Vjačeslav Usmanov	changed CM_01_BayesCalibration.ipynb