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Quantitative risk assessment and optimization of process intervention parameters for French raw milk soft cheese.

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Context

This study is a part of the European project ArtiSane-Food that aims at controlling food-borne pathogens in artisanal fermented food of meat and dairy, origin developed in the Mediterranean region. As a participating country one of the main objective for France is to allow the continuation of the production of raw milk soft cheeses, which is today potentially at risk due to future European regulations. At the French national level this project is in collaboration with ANSES, CNIEL, CentraleSupélec - Université Paris-Saclay and organizations from the dairy industry.

Problem Statement

The primary goal is to establish efficient intervention strategies, in order to “economically” reduce the risk of Haemolytic Uremic Syndrome (HUS) caused by Shiga-Toxin producing Escherichia coli (STEC) present in raw-milk soft cheese. Intervention strategies in cheese making:

• Pre-harvest milk sorting:
  - STEC and E. coli strains follow same fecal route!
  - A bulk tank of milk is tested with probability $p_{\text{t-test}}^{\text{milk}}$
  - Farms with E. coli conc. $> P_{\text{limit}}$ are rejected
  - $C_{\text{t-test}}$: Cost of testing and rejecting bulk tank milk

• Post-harvest cheese sampling:
  - A batch of cheese is tested with probability $p_{\text{t-test}}^{\text{cheese}}$
  - From a single batch $n_{\text{sample}}$ cheeses are tested for presence of STEC
  - $C_{\text{t-test}}$: Cost of testing and rejecting cheese batches

The aim is to find the optimal values of the process intervention parameters $(x_1, x_2, x_3)$, that minimize the risk of HUS and the costs ($C_{\text{t-test}}$).

Quantitative Risk Assessment (QRA)

QRA based on model proposed by $\gamma$

• Farm module + Pre-harvest step
  - STEC conc. $y_{\text{stec}}$ in farm milk is computed $y_{\text{stec}} = y_{\text{stec}}(\text{farm})$

• Cheese module
  - Evolution of STEC is modeled with ODEs $\frac{dy}{dx} = \mu_{\text{bact}}(t) - \gamma(t) \cdot \left(1 - \frac{y(t)}{P_{\text{limit}}}\right)$

• STEC cells form colonies (clusters) inside cheese
  - No. of colonies (Poisson): $N_{\text{colony}}$
  - Size of colonies (LogNormal): $y_{\text{colony}}$

• Consumer module
  - Batch risk is computed using a dose-response model: $R = \sum_{x} N_{\text{colony}} y_{\text{colony}}$

Bi-objective optimization

We consider the bi-objective optimization problem

$$
\min_{x \in \chi} f(x)
$$

where, $f = (f_1, f_2)$

• Not necessarily has a unique solution $x^* \in \chi$, in presence of conflicting objectives

• The solution set $P$ consists of Pareto optimal points

$$P = \{x \in \chi : \exists \hat{x} \in \chi, f(x) < f(\hat{x})\}$$

where $f^* < f^0 \Rightarrow f_i^* \leq f_i^0, \forall i$, with at least one of the inequalities being strict

Experimental results

• Minimizing $f$ over the input space $\chi$
  - $n_{\text{sample}} \in \{5, 10, 20, 30, 50\}$
  - $P_{\text{limit}} \in \{1/10, 1/20, 1/30, 1/40, 1/50\}$
  - $p_{\text{t-test}}^{\text{milk}} \in \{0.1, 0.2, 0.3, 0.4, 0.5\}$

• True Pareto front: estimated using 5000 samples for each of $5 \times 5 \times 5 \times 5 = 625$ input points

• Initial design size = 60, evaluation budget = 40
• Batch size per iteration = 300

• With PALS using significantly less (300 × 300) evaluations, the user can provide the following insights
  - Most of the dominated (red) points are well classified
  - The points corresponding to $P$ remain unclassified (blue)

References


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