A Behaviour Digital Twin for Residential Demand Response

Modelling intention and motivation to improve the prediction of the likelihood of reaction to behavioural triggers

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Residential Demand Response

Motivation and Definition

• Going forward European “consumers should be able to benefit from directly participating in the [energy] market, in particular by adjusting their consumption according to market signals”[1]

• This can be supported by suitable residential demand response schemes, which aim at “reducing or shifting […] electricity usage during peak periods in response to time-based rates or other forms of financial incentives”[2]

Residential Demand Response

Key challenges

• Financial incentives for the individual household are limited and thus far have produced limited outcomes \[^3,4\]

• Therefore, “market participants engaged in aggregation are likely to play an important role as intermediaries between customer groups and the market” \[^1\]


Residential Demand Response

Key challenges

• However, these “independent aggregators”[1] will depend on their customers’ willingness to adapt their behaviour when required by the grid

• The flexibility available to the market therefore not only depends on available flexibility assets but crucially also on the motivation and intentions of participating individuals

Aggregators sell household flexibility to the grid
Behaviour Digital Twin

They use digital twins to mirror available energy assets

Grid

Household

Aggregator

Household

Digital Twin
Behaviour Digital Twin

Control of household appliances requires end-user interaction
A residential digital twin should also consider end-user behaviour.
Behaviour Digital Twin

Intention and motivation

• The likelihood of an individual to respond to a request depends on their intention and motivation [5]
• Psychological behaviour models have been developed to assess such variables through empirically validated inventories [6,7]

Theory of Planned Behaviour

Assessing short-term intention

• Intention is the “subjective probability of a person to perform the behaviour in question in respect to a given object”\textsuperscript{[5]}

• To measure the behavioural intention the TPB proposes a framework for assessing a person’s beliefs through structured questionnaires

Theory of Planned Behaviour

Example questions to assess energy flexibility beliefs

Validated Inventories

- Behavioural Beliefs
  - It is important to me to adjust my behaviour according to energy availability to support a more environmentally friendly life-style.

- Normative Beliefs
  - Most of my friends would adjust their behaviour according to the availability of energy.

- Control Beliefs
  - It sounds easy to use energy at the right time.
Theory of Planned Behaviour

A psychological model to calculate behavioural intentions

- **Validated Inventories**
  - Behavioural Beliefs
  - Normative Beliefs
  - Control Beliefs

- **Explainable intermediary variables**
  - Attitudes towards the behaviour
  - Social and Subjective Norms
  - Perceived Behavioural Control

- **Model parameters**
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  +
  +

- **Intention**
The Theory of Planned Behaviour

Operationalisation of the model

**Validated Inventories**

- \( \{ e_{pi}^{BB} | 1 \leq i \leq n_A \} \)
- \( \{ e_{pi}^{NB} | 1 \leq i \leq n_{SN} \} \)
- \( \{ e_{pi}^{CB} | 1 \leq i \leq n_{PBC} \} \)

**Explainable intermediate variables**

- \( A_p = \sum_{i=1}^{n_A} q_i^{BB} e_{pi}^{BB} \)
- \( SN_p = \sum_{i=1}^{n_{SN}} q_i^{NB} e_{pi}^{NB} \)
- \( PBC_p = \sum_{i=1}^{n_{PBC}} q_i^{CB} e_{pi}^{CB} \)

**Model parameters**

- \( w^A \)
- \( w^{SN} \)
- \( w^{PBC} \)

**Equation**

\[
BI_p = \frac{w^A A_p + w^{SN} SN_p + w^{PBC} PBC_p}{3}
\]
Self-Determination Theory

Assessing long-term motivation

• Motivation is seen as a more general tendency towards a specific subject area\(^8\)

• To measure the motivation the SDT proposes a framework for determining a person’s relative autonomy by assessing their goal aspirations through structured questionnaires

Self-Determination Theory

Example questions to assess energy flexibility goal aspirations

- I simply enjoy supporting the environment, even if that means that I have to adapt my behaviour.
- Adjusting my behaviour in a way that it matches energy availability is good for the environment.
- I would feel bad about myself if I didn’t adjust my behaviour depending on if energy is available or not.
- It helps my image in the neighbourhood and community to show energy flexibility.

Validated Inventories
Self-Determination Theory

A psychological model to calculate motivation

Validated Inventories
- Intrinsic goal aspirations
- Identified goal aspirations
- Introjected goal aspirations
- External goal aspirations

Explainable intermediary variables
- Intrinsic Regulation
- Identified Regulation
- Introjected Regulation

Model parameters
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Motivation

Succeeding Together

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Self-Determination Theory

Operationalisation of the model

Validated Inventories

- $\{a_{pi}^{INT} | 1 \leq i \leq n_{INT}\}$
- $\{a_{pi}^{ID} | 1 \leq i \leq n_{ID}\}$
- $\{a_{pi}^{INTRO} | 1 \leq i \leq n_{INTRO}\}$
- $\{a_{pi}^{EXT} | 1 \leq i \leq n_{EXT}\}$

Explainable intermediary variables

- $R_{p}^{INT} = \sum_{i=1}^{n_{INT}} q_{i}^{INT} a_{pi}^{INT}$
- $R_{p}^{ID} = \sum_{i=1}^{n_{ID}} q_{i}^{ID} a_{pi}^{ID}$
- $R_{p}^{INTRO} = \sum_{i=1}^{n_{INTRO}} q_{i}^{INTRO} a_{pi}^{INTRO}$
- $R_{p}^{EXT} = \sum_{i=1}^{n_{EXT}} q_{i}^{EXT} a_{pi}^{EXT}$

Model parameters

- $w^{INT}$
- $w^{ID}$
- $w^{INTRO}$
- $w^{EXT}$

$RAI_p = 2w^{INT} R_{p}^{INT} + w^{ID} R_{p}^{ID} - w^{INTRO} R_{p}^{INTRO} - 2w^{EXT} R_{p}^{EXT} \over 6$
Predicting the Likelihood to act

Combining intention and motivation

Attitudes towards the behaviour

Social and Subjective Norms

Perceived Behavioural Control

Intention

Motivation

Predicted likelihood to act

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Identified Regulation

Introjected Regulation

External Regulation

Intrinsic Regulation
Predicting the Likelihood to act

Observing the contradiction with actual behaviour

- Attitudes towards the behaviour
- Social and Subjective Norms
- Perceived Behavioural Control

Intention

Motivation

Predicted likelihood to act

Contradiction

- Intrinsic Regulation
- Identified Regulation
- Introjected Regulation
- External Regulation

Observed behaviour
Predicting the Likelihood to act

Continuous minimisation of contradiction by adapting weights

- Attitudes towards the behaviour
- Social and Subjective Norms
- Perceived Behavioural Control

Intention

Motivation

Predicted likelihood to act

Intention - action gap

Contradiction

Observed behaviour

Intrinsic Regulation
Identified Regulation
Introjected Regulation
External Regulation

Succeeding Together
Predicting the Likelihood to act

Every individual’s likelihood to act can be calculated

\[ P_{ap} = \frac{1}{1 + e^{(IAG_a - BI_p - RAI_p)/\gamma}} \]
Summary

Behaviour Digital Twin

• Model predictive control is challenging to implement in aggregated residential settings
• Predicting the probability that a person will react to a trigger message combined with the available flexibility is vital for deciding whom to target and when in a dynamic residential demand response scenario
• Assessing intention and motivation and continuously adapting to actual observed behaviour is a promising approach
• Psychological inventories provide a validated methodology for measuring key variables and can be operationalised into a Behaviour Digital Twin model
Thank you for your attention

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