A Model for Designing Personalized and Context-Aware Nudges

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Abstract: Nudging is a popular approach used to influence people to change their behavior towards a desirable goal. To be effective, nudges should be tailored to the user's specific needs based on user profile, current behavior, and context information. In this paper, we target the questions of *what to nudge for* and *when to nudge*, and how nudges can be automatically designed at a time when the user needs nudging. We present a model for personalized and context-aware nudge design that is adaptive in that it continuously tailors the set of relevant activities and the time for creating a nudge to the user's needs for behavioral change. The model follows a just-in-time approach, where nudges are created at the time when nudging is needed, based on the user's current situation.

1 INTRODUCTION

Nudging is a technique used to influence people to change behavior towards a desired outcome, e.g., to adopt healthier or more environmentally friendly habits. Behavioral change is the process of adopting new habits or modifying existing ones to achieve a specific goal, and nudging is an effective tool for promoting behavioral change involving psychological factors that influence human behavior without restricting their freedom of choice (Thaler and Sunstein, 2008).

Our focus is on personalized and context-aware digital nudges, called *smart nudges*, where digital technology is used to influence or guide people's behavior (Karlsen and Andersen, 2019). *Personalized nudging* refers to the use of tailored nudges based on the user's specific characteristics, activity history, and preferences, while *context awareness* uses people's situation and environment to identify opportunities, limitations, and obstacles, to further tailor nudging to the needs of the user.

To facilitate behavioral change, nudging will challenge the user by motivating for activities that brings the user closer to the nudging goal. To do so, a nudging system will continuously keep track of the user's activities, preferences, achievements, and environment, to design relevant and timely nudges that are presented to the user, e.g., on a mobile device.

The idea behind tailored nudging is that people are more likely to respond positively to nudges that are relevant and meaningful to them, rather than using generic or "one-size-fits-all" nudges (Schneider et al., 2018; Peer et al., 2020; Mills, 2022). However, a challenge when designing tailored nudges is to determine what to nudge for and when to nudge.

This paper presents a practical model for how to design smart nudges based on the user's current behavior and situation. We focus on *what to nudge for* and *when to nudge*, and suggest a general approach to select activity and time frame for a nudge. We exemplify how the proposed solution can be used in two different use cases; for physical activity nudging and green transportation nudging.

In the following, we first present smart nudges, nudge design, and the two use cases. We describe several factors that influence nudge design, including level of behavior, behavioral progress, activity patterns, reactions to previous nudges, capability, and opportunity. This is followed by a description on how activity and time frame for nudges are selected. Finally, we discuss our approach and conclude.

2 BACKGROUND

This section describes smart nudges, principles for smart nudge design, and two use cases that will exemplify how our generic model for nudge design can be applied to different nudging systems.

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2.1 Smart Nudges and Nudge Design

A *smart nudge* is a personalized and context-aware digital nudge, described through a set of components, including an *activity* selected for the nudge, a *time frame* for when the activity is suggested done, some *influence* that motivates the user to do the activity, and some practical information useful when following the nudge.

Every component of a smart nudge can be tailored to the user's need for nudging. A user profile (including, e.g., user interests, capabilities, activity history, and reactions to previous nudges) and context information (describing the user's environment and surroundings) are used to determine which activity and practical information to include, which time frame to target, and how to influence the user.

Nudges are typically offered to the user through an application on a mobile phone, and a combination of back-end and edge computing determines when and what to nudge for through monitoring, selecting, and analysing data from various sources, e.g., IoT sensors, third-party data sources, mobile phone sensors, and stored user data (Andersen et al., 2018).

Designing a nudge involves several tasks, as illustrated in Figure 1. In this paper, we focus on the details concerning selecting activity and time frame for nudges. In paper (Karlsen and Andersen, 2024) we describe the task of triggering smart nudges, paper (Dalecke and Karlsen, 2020) focus on the influence part of nudge design, while we are currently working on details concerning content selection and nudge presentation.

The design tasks are influenced by a set of nudge design principles, presented in Table 1 and previously described in (Karlsen and Andersen, 2022), that guide the selection of activity and time frame.

Table 1: Principles for smart nudge design.

Challenge	Nudging must challenge the user to choose activities that improve the user's behavior.
Consolidate	After improving behavior, the user must be stabilized on the new level of behavior. For a period the user is not challenged.
Progress	Challenging the user will continue after a consolidate period. Given there is still room for improvement.
Variation	The user should over time be given a variety of nudges, to make nudging interesting and introduce new activities.
Timeliness	A nudge should be given at a time when the user can react to it and when the nudge can be effective.
Safety and feasibility	A nudge must avoid activities that are dangerous or impossible for the user to do.

2.2 Use Cases

2.2.1 Physical Activity Nudging

Nudging people to be sufficiently physically active is a desirable goal since regular physical activity is a known protective factor for the prevention and management of physical and mental diseases (WHO, 2016).

A nudge will present the user with a suggestion for an activity and a time frame for doing it. For the user to improve, nudging must suggest behavior that goes beyond the user's current behavior, e.g., by nudging the person to (i) be active more often, (ii) be active for longer periods, or (iii) engage in more challenging activities.

We distinguish between generic and specific nudges. A *generic nudge* suggests an activity (such as walking or cycling), and leaves it to the user to decide how and where the activity is performed. The nudge can optionally suggest a time frame, distance, or duration of the activity. An example nudge is: *"It's time for a walk. The weather is nice and you have time this afternoon."*.

A *specific nudge* suggests a trail, that has a location, route, and destination, and is characterized by properties such as activity type, distance, estimated duration, and difficulty. For example, a nudge can suggest a hike to Mount X, which has a 5.8 km long trail, elevation gain of 553 m, an estimated duration of 2.5 hours, classified as hard, and has a spectacular view from the top. Description and properties of such trails can be found on online sources such as AllTrails.com[1], and can be used for creating specific nudges.

2.2.2 Green Transportation Nudging

The goal of green transportation nudging is to motivate the user to choose environmentally friendly transportation means. This is desirable because of the urban challenges of increased traffic, congestion, air pollution, and global-scale issues of climate change and global warming (Comission of the European Communities, 2007).

When the user needs to move between two locations, origin (O) and destination (D), nudging can motivate the user to choose alternatives to, e.g., private car usage. Relevant alternatives depend on, e.g., the availability of public transportation, whether the

[1] https://www.alltrails.com

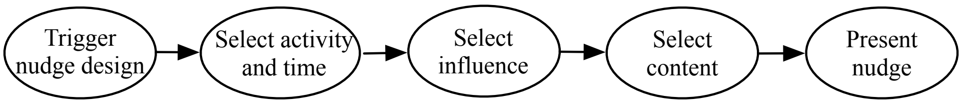

Figure 1: Tasks in a nudge design process.

distance between *O* and *D* allows walking or cycling, and the user's ability to use the different transportation means.

Alternatives to using the private car include walking, cycling, public transportation, and the use of motorbikes and electric scooters. An alternative can also be to optimize and limit private car usage through carpooling, incentive parking (park and ride), and finding the most efficient driving route to the destination.

Available transportation means are ranked according to how environmentally friendly they are, and a nudge will suggest that the user selects a transportation alternative that is better than what the user normally prefers between *O* and *D*.

2.2.3 Related Work

The goal of nudging is to motivate people to change their behavior in some direction. As motivation is an important feature of nudging, much focus has been on the influence component, as seen in, e.g., (Caraban et al., 2019; Forberger et al., 2019; Caraban et al., 2020; Villalobos-Zúñiga and Cherubini, 2020; Bergram et al., 2022). However, it is equally important to focus on other components of a nudge. In this paper, we target the questions of *what to nudge for* and *when to nudge*, and how timely nudges can be automatically designed. A *just-in-time nudge design* approach is necessary since we tailor nudges to the user's behavior, situation, and environment, which is known only at the time of nudging.

Different authors have described digital nudge design through theoretical models or frameworks intended for designers or practitioners (Meske and Potthoff, 2017; Mirsch et al., 2018; Schneider et al., 2018; Purohit and Holzer, 2019). In contrast, we describe a model that targets automatic and adaptive nudge design in that it continuously tailors nudges to the user's current needs for behavioral change.

The main focus for nudging has up until recently been on one-size-fit-all nudges (Anagnostopoulou et al., 2020; Peer et al., 2020). However, the importance of personalization in designing effective nudges has been recognized by several authors, e.g., (Schöning et al., 2019; Peer et al., 2020; Mills, 2022), and experiments (Peer et al., 2020; Mills, 2022) show that personalized nudges can lead to more effective nudging compared to non-personalized nudges. Personalized nudging is a topic in need of more research (Caraban et al., 2019; Jesse and Jannach, 2021; Bergram et al., 2022), and we target this important topic through our model for nudge design.

Our approach to personalized and context-aware nudging is different from other approaches we are aware of, in that nudges are *automatically designed* and *adaptively tailored* to the current need of the user, based on continuous monitoring of user behavior and environment. The user is gently challenged to improve, based on an *adaptive goal*, and the nudging system will continuously distinguish between impossible and possible activities for the user.

3 FACTORS INFLUENCING NUDGE DESIGN

Smart nudging requires knowledge about the user's current behavior and behavioral change. This is obtained by monitoring user activities relevant to the nudging goal. This section describes how the user's Level of Behavior is measured, how Behavioral Progress is determined, how Activity Patterns are useful for nudge design, and how reactions to previous nudges influence nudging. Nudge design is also influenced by user capability (i.e., the ability to do an activity) and opportunity (i.e., how context can make an activity possible or not). Table 2 summarises these factors and describes how they influence smart nudge design.

3.1 Level of Behavior and Behavioral Progress

This section presents a general description of Level of Behavior and Behavioral Progress, followed by examples of how the concepts are used in the two use cases.

3.1.1 General Description

Level of Behavior (LoB) refers to how well a user behaves with respect to the nudging goal, e.g., how physically active or environmentally friendly the user is. LoB is measured using an ordinal scale, e.g., *Very Low, Low, Medium, Good, Excellent*.

The user's current LoB is determined by monitoring and assessing all activities relevant to the nudg-

Table 2: Factors influencing the selection of activity and time frame during nudge design.

Factors	Description	Effects on nudge design
Level of Behavior (LoB)	A measure of how well the user behaves regarding the nudging goal.	LoB is used as a basis for setting an *ActivityGoal*, determining *behavioral progress*, and keeping track of how user behavior changes over time.
Behavioral progress	As the user's behavior change, the progress is described as *improved*, *stable*, or *decreased*.	Determines if the nudging system should challenge the user to improve or help the user to stay on the current activity level.
Activity pattern	Describes recurring activities that happen in a systematic way.	Can detect activities the user is predominantly doing, when and under which circumstances activities are normally done. Identifies preferred activities and time frames, and can guide how to improve behavior.
Reactions to nudges	Monitor reactions to nudges and register which nudges the user accepts and rejects.	Knowing which activities, time frames, and influence types the user responded positively to, contributes when selecting components for new nudges.
User capability	The individual's physical and psychological capacity to engage in an activity.	Distinguishes between activities the user is unable to do (i.e., impossible activities) and activities the user is capable of doing.
Opportunity	The factors that lie outside the individual that make an activity possible or not	An activity can be impossible because of permanent/long-lasting circumstances (e.g., lack of equipment) or temporary circumstances (e.g., challenging weather conditions).

ing goal. As behavior changes over time, LoB is determined for discrete time periods (e.g., per week or month), and LoB for the latest period determines if the user needs to improve or if the best LoB is reached and the user should be nudged only to continue on the same behavioral level.

User activity is in our use cases measured using a numerical value. Each activity is given a value that reflects how well it supports the nudging goal and $UserActivity(P)$ represents the total value of all the user's activities in period P. Level of Behavior for P, i.e., $LoB(P)$, is determined by mapping the $UserActivity(P)$ value to the LoB scale.

To follow the principle of *challeng the user*, the nudging system automatically sets and adjusts a goal (denoted *ActivityGoal*) for the next time period P. If the goal is met for period P_i, *ActivityGoal* is slightly increased for the next period P_{i+1}.

Behavioral Progress guides the "aggressiveness" of the system, by determining if the system should challenge the user to improve or help the user to stay on the current activity level. Three states describe behavioral progress, i.e., *improved, stable*, and *decreased*, and enables the system to design nudges so that the principles of *consolidate* and *progress* are followed.

When the user reaches a higher LoB (e.g., when going from *Medium* to *Good* on the LoB scale), the progress state, *PrState*, is set to *improved* and the system suspends, for a period, the automatic adjustment of the goal, as nudging will focus on consolidating the user on the newly reached level. After a while, the user enters a *stable* stage and the system can again challenge the user by gently increasing the *ActivityGoal* value. If user behavior declines, the state is set to *decreased*, the value of *ActivityGoal* remains unchanged, and the user will be challenged in order to improve.

Formula 1 describes how the *ActivityGoal* value is automatically adjusted with an improvement factor *Impr*. The *ActivityGoal* is increased only if the user has reached the activity goal the last time period, and the user is not in an *improved* state.

$$\begin{aligned} If\, UserActivity(P) &\geqslant ActivityGoal \\ AND\, PrState &\neq \text{“}improved\text{”} \\ then\, ActivityGoal &= ActivityGoal + Impr \end{aligned} \tag{1}$$

To keep track of how user behavior changes over time, historic values of Level of Behavior are stored in a *History of Behavior*. The history can, e.g., show whether user behavior improves over time or if the time of year has any impact on behavior.

3.1.2 Physical Activity Nudging

Physical activity can be measured using step count and , $UserActivity(P)$ represents the total number of steps for all activities performed during P. For activities such as walking or running, a pedometer is used for simply counting steps. Other types of activities (e.g., swimming or climbing) can be manually registered by the user and converted to steps using a step conversion factor. In Formula 2 the number of steps are calculated for an activity a.

$$Steps(a) = StepConversionFactor(a) * Duration(a) \tag{2}$$

The number of steps obtained from a pedometer does not measure user effort or exercise intensity. Using number of steps per minute or complementing the pedometer with a heart rate monitor are two approaches to get indications of effort or intensity. If effort or intensity is available, number of steps can be normalized, by multiplying with an effort factor before being added to the $UserActivity(P)$ value, as described in Formula 3.

$$NormalizedSteps(a) = steps(a) * effort(a) \quad (3)$$

The *ActivityGoal* is also given in number of steps, and the user can be challenged by expecting more steps the next period. To reach the new goal, the system may nudge for longer walks, more challenging exercises where user effort increases, or nudge more often to increase the frequency of physical activity.

Based on health organizations' recommendations for physical activity, mapping between $UserActivity(P)$ value and the LoB scale can be adapted according to, e.g., age and capabilities of the user.

3.1.3 Green Transportation Nudging

Determining *Level of Behavior* regarding green transportation includes monitoring or registering the type of transportation chosen in every travel situation.

A travel is described through a set of properties, including (*O, D, Time, TMeans*), where *O* and *D* represent origin and destination, *Time* represents departure time, and *TMeans* the transportation means used for the travel. Each type of transportation means is characterized by its environmental friendliness (EF) using an EF-value in the range [0,1], where the higher the value, the more environmentally friendly the transportation means is.

$UserActivity(P)$ represents the average EF-value over every transportation means used in period *P*. This is expressed in Formula 4, using the set $Travel(P)$ that includes all EF-values of travels made by the user in *P*.

$$UserActivity(P) = \frac{\sum_{x \in Travel(P)} x}{|Travel(P)|} \quad (4)$$

$Travel(P) = \{x | x \text{ is the EF-value of a travel in } P\}$

Both $UserActivity(P)$ and *ActivityGoal* represent EF-values in the range [0,1]. To help the user reach the goal, nudging can suggest more environmentally friendly transportation means (with a better EF-value) compared to what the user has previously chosen.

The user may have different habits when traveling between different locations, e.g., the user may prefer to walk to work, while using the car when traveling with kids or going shopping. Knowing the user's LoB for recurring (O,D) pairs can be helpful for identifying where improvements can be suggested.

Consequently, user activity is determined per (O,D) pair (i.e., $UserActivity_{(O,D)}(P)$) using Formula 5, where $Travel_{(O,D)}(P) \subseteq Travel(P)$. This makes it possible to register LoB per (O,D) pair and have an (O,D) specific goal, i.e., $ActivityGoal_{(O,D)}$.

$$UserActivity_{(O,D)}(P) = \frac{\sum_{x \in Travel_{(O,D)}(P)} x}{|Travel_{(O,D)}(P)|} \quad (5)$$

$Travel_{(O,D)}(P) = \{x | x$ is EF-value of a travel between O and D in $P\}$

Generally, taking the bus or a car gives a lower EF-value compared to walking and cycling. However, if the distance is too long and walking/cycling is not practical or possible, the bus (or other public transportation means) can be considered the greenest choice. Also, the time of day may determine what to expect from the user and what the nudging system can recommend. Walking late at night may not be safe, and therefore not an option. Taking the bus, or perhaps even a taxi, will in this situation be considered the greenest alternative. In each situation, the greenest alternative is given the best EF-value.

3.2 Activity Patterns

This section presents a general description of activity patterns used in nudging, followed by examples of how activity patterns are detected in the two use cases.

3.2.1 General Description

Activity Patterns represent information on user activities detected through monitoring and/or manual registration of activities. Generally, an activity pattern describes recurring activities that happen in a systematic and predictable way and, with respect to nudging, targets activities that are relevant to the nudging goal.

As nudging should support the user to improve behavior, we expect activity patterns to change over time. Therefore, activity patterns are detected for different time periods (e.g., weekly or monthly patterns), where differences between patterns can uncover changes in behavior.

An activity pattern identifies activities the user is predominantly doing, characteristics of these activities, when and under which circumstances (e.g., weather conditions) activities are normally done. Knowing the user's current activity pattern and level of behavior is the key to knowing how to nudge the user. The activity pattern is used as *baseline* when selecting activities for a nudge while avoiding activities or circumstances that represent a radical change for the user.

User *preferences* can to some extent be favored in nudge design, given that it does not conflict with the goal of improving behavior. The user may, for example, be inclined to accept a nudge suggesting a familiar activity or an activity with properties that do not deviate too much from the user's current behavior.

3.2.2 Physical Activity Nudging

Activity patterns provide information on which activities the user prefers, habits concerning when to exercise, and the duration and/or distance of previous activities. When designing new nudges, this is used as a basis to determine which activities to nudge for and when to nudge.

To identify activity patterns, we focus on activities (or exercises) that last more than a certain amount of time (e.g., 15 minutes). This is different from determining Level of Behavior, where we include all steps during a time period.

Exercises can be identified by analyzing i) *step count data*, where an *exercise* is identified as continuous activity (i.e., steps) exceeding a certain amount of time, and ii) *manually registered exercises*.

To manually register exercises, many tracking devices (such as FitBit[2], Oura ring[3], and Apple Watch[4]) allow users to select an activity type (such as walking, cycling, swimming, or climbing) and register start time and duration. An activity tracker can also support the user by automatically detecting certain types of exercises.

The two complementary approaches; step count analysis and analysis of manually registered exercises, may both find exercises not detected by the other. For example, step count analysis will not detect swimming and climbing, but may detect (walking) exercises overseen or forgotten by the user, and therefore not manually registered. Also, some exercise types (such as walking and running) may be detected by both approaches. As part of a data cleaning process, duplicate exercises are identified and merged by comparing the time property.

An exercise is described through a set of properties, including *activity type*, number of *steps*, *distance*, *duration*, *elevation*, and *time* of day/week when the exercise took place. Activity patterns can provide frequency of activity types (to identify favorites or activities the use never do), at which time the user tends to be active (indicating when it may be useful to nudge), and relations between activity and time (e.g., which activities are preferred at certain times of week/year).

For each type of activity, distance, duration, and elevation can be described using statistical values such as average, distribution, minimum, and maximum, where minimum and maximum identify the currently easiest and most challenging experience (e.g., shortest and longest distance), while average and distribution are used for identifying the user's normal activity.

Activity patterns can be combined with context data (e.g., weather conditions or level of pollution) to detect which activities are predominantly done at a given condition.

3.2.3 Green Transportation Nudging

Activity patterns provide information on recurring travels between (O,D) pairs, including preferred transportation means and departure times. Recurring travels represent traveling habits, such as going to work at approximately the same time every weekday, picking up kids at school, or going to the gym at certain times during the week. As users may have different habits when traveling between different locations, an activity pattern for each recurring (O,D) pair (denoted $ActivityPattern_{(O,D)}$), is identified.

The user's movements, from one location to another, departure, and traveling time can be monitored using some activity tracking devices. Also, transportation means can to some extent be inferred based on monitored data. However, to obtain accurate travel information, the user must manually register the selected transportation means and departure time.

The activity patterns are used as a basis for selecting transportation means and time frame when designing new nudges, where the user can be challenged to use more environmentally friendly transportation means compared to the preferred choice, while patterns concerning departure time indicate when a nudge can be useful.

3.3 Reactions to Nudges

By registering reactions to nudges, the system can learn which nudges were accepted or rejected by the user. Accepted nudges reveal which nudges the user found useful, while rejected nudges reveal what the user did not find tempting or useful, where, e.g., the timing was wrong, or the activity too challenging or not interesting. Since there are many reasons for rejecting a nudge, it is useful with a response from the user on what caused the rejection.

[2]https://fitbit.com
[3]https://ouraring.com
[4]https://www.apple.com/watch/

For both physical activity and green transportation nudging the set of accepted nudges may over time reveal patterns of which activities tempted the user, and which influence types the user reacted positively to. The set of rejected nudges may, on the other hand, identify activities the user is not interested in, and possibly also influence types that do not motivate the user. An activity that is repeatedly rejected should be suspended from nudging for a period.

3.4 Capability and Opportunity

The work of (Michie et al., 2011) describes a *behavior system*, where capability, opportunity, and motivation interact to generate behavior. Capability and opportunity are factors that influence motivation, while behavior is influenced by all three components. Motivation is in our work represented by the influence component in a nudge, while capability and opportunity impact the selection of activity and time frame for a nudge.

3.4.1 Capability

Capability is defined as the individual's physical and psychological capacity to engage in a suggested activity, and includes having the necessary knowledge and skills to do the activity (Michie et al., 2011).

In a nudging system, the user can register personal capabilities and/or capability constraints, such as physical disabilities and lack of skills. The user's status regarding capability makes certain activities permanently or temporarily impossible. Activities can become possible if the capability status change, e.g., if the user recovers from a temporary disability or obtains the necessary skills. User capability contributes to distinguishing between activities that are impossible for the user, and activities that can be included in a nudge.

3.4.2 Opportunity

Opportunity is defined as all the factors that lie outside the individual that make a behavior possible or not (Michie et al., 2011). This includes physical circumstances (such as access to resources or facilities), environmental and social factors that support or hinder activities. Opportunity covers a large number of different circumstances that affect the user's ability to perform an activity, and therefore affect the choice of activity when designing a nudge.

We identify an *obstacle* as a situation which makes it impossible to go through with an activity. The reason can, e.g., be the lack of equipment (such as bicycle or skis), lack of facilities or services (such as safe outdoor spaces or public transportation), or harmful or hazardous situations (such as severe weather conditions) that make activities potentially dangerous.

An obstacle can be long-lasting or temporary. A long-lasting obstacle is removed only if some fundamental change is made, e.g., if new equipment or facilities are made available, or if the user change location where circumstances are different. A temporary obstacle ends as soon as the harmful situation is over. Long-lasting obstacles can be manually registered by the user, while temporary obstacles are detected based on monitoring the user's surroundings.

4 SELECTING ACTIVITY AND TIME FRAME FOR THE NEXT NUDGE

This section describes factors relevant when selecting a suitable activity and time frame during nudge design. In the following, we describe i) how the need for nudging is detected, ii) how the set of possible activities for a nudge is identified, and iii) how the selection of activity and time frame can be done.

4.1 Identifying an Activity Gap

4.1.1 General Description

A nudge can be triggered by certain situations that indicate the need for a gentle push towards the nudging goal. An important reason for nudging is that the user's current Level of Behavior is insufficient to reach the $ActivityGoal$.

Formula 6 calculates $ActivityGap(P)$, which represents a measure of the activity needed to reach the goal for the current (unfinished) time period, P.

$$ActivityGap(P) = ActivityGoal - PredActivity(P) \quad (6)$$

$PredActivity(P)$ represents the amount of activity predicted to be done in P, including already *completed activities* and *expected activities* in P. An expected activity can be a recurring activity, detected through the user's activity pattern, or an activity the user has committed doing in P.

The $ActivityGap(P)$ can be calculated from the first day of P, and as both completed and expected activities will change during P, $PredActivity(P)$ and $ActivityGap(P)$ must be regularly recalculated to reflect the user's achievements during P.

Knowing the $ActivityGap(P)$, makes it possible to plan and design a set of nudges for P that collectively helps the user to reach the activity goal. As the

$ActivityGap(P)$ value is updated during P, the set of planned nudges must also be updated.

The generic Formula 6 applies to both use cases. However, as described in the following Sections 4.1.2 and 4.1.3, $ActivityGap(P)$ and $PredActivity(P)$ are calculated differently in the two cases.

4.1.2 Physical Activity Nudging

For physical activity nudging, the $ActivityGap$ determines the additional number of steps needed for the user to reach the $ActivityGoal$.

Predicted activities, $PredActivity(P)$, is calculated as seen in Formula 7, where $CompActivity(P)$ and $ExpActivity(P)$ represent the number of steps for completed and expected activities in P, respectively.

$$PredActivity(P) = CompActivity(P) + ExpActivity(P) \tag{7}$$

The $ActivityGap(P)$ is calculated using Formula 6, and nudging is needed if $ActivityGap(P) > 0$.

4.1.3 Green Transportation Nudging

For green transportation nudging, $ActivityGoal$, $ActivityGap$, and all travels are measured using the EF-value. Predicted activities, $PredActivity(P)$, is calculated as a combined average EF-value over all completed and expected travels, see Formula 8. The calculation is based on two sets of EF-values, representing the completed travels, $CompTr(P)$, and the expected travels, $ExpTr(P)$.

$$PredActivity(P) = \frac{\sum_{x \in CompTr(P)} x + \sum_{y \in ExpTr(P)} y}{|CompTr(P)| + |ExpTr(P)|} \tag{8}$$

$CompTr(P) = \{x | x$ is the EF-value of a completed travel in period $P\}$
$ExpTr(P) = \{y | y$ is a predicted EF-value of an expected travel in period $P\}$

The expected transportation means, and thus the expected EF-value, for a travel between O and D is based on the user's previous behavior, such as the preferred transportation means for (O,D) the last few time periods.

Nudging is needed if $ActivityGap(P) > 0$, and, at the end of P, the $ActivityGoal$ is reached if $ActivityGap(P) \leqslant 0$.

When using (O,D) specific activity goals, i.e., $ActivityGoal_{(O,D)}$, activity gaps can be determined per (O,D) pair (i.e., $ActivityGap_{(O,D)}(P)$) using Formula 9, where $PredActivity_{(O,D)}(P)$ is calculated as in Formula 8 but in this case using the two sets $CompTr_{(O,D)}(P)$ and $ExpTr_{(O,D)}(P)$ which only includes completed and expected travels between (O,D) in period P.

$$ActivityGap_{(O,D)}(P) = ActivityGoal_{(O,D)} - PredActivity_{(O,D)}(P) \tag{9}$$

4.2 Identifying Possible Activities

4.2.1 General Description

In (Karlsen and Andersen, 2022) we classify activities as *impossible*, *possible*, *unlikely* (to be accepted by the user), and *probable* (that have the potential to be accepted by the user). Table 3 describes each class of activity, while Formula 10 shows the relation between the classes, where U represents a user and A all available activities.

Table 3: Classification of activities.

Impossible	Activities the user is not capable of doing. Identified based on user capability and opportunity.
Possible	Activities the user is capable of doing. $Possible(A,U)=Probable(A,U) \bigcup Unlikely(A,U)$
Probable	Activities the user has done in the past and is likely to do in the future. Likely to be accepted when suggested in a nudge.
Unlikely	Activities the user has never done, challenging and/or repeatedly rejected activities. Identified based on the user's activity pattern and reactions to previous nudges.

$$\begin{aligned} Possible(A,U) &= A - Impossible(A,U) \\ Probable(A,U) &= Possible(A,U) - Unlikely(A,U) \end{aligned} \tag{10}$$

The classification is user-specific, based on the user's activity pattern and reactions to previous nudges, where a challenging or repeatedly rejected activity can cause the activity to be classified as unlikely. Also, capability and opportunity can make an activity temporarily or permanently impossible.

4.2.2 Physical Activity Nudging

For the physical activity use case, activity patterns provide frequency of activity types (such as walking, cycling, and swimming), and identifies for each activity type, minimum, average, and maximum values for properties such as distance, duration, and elevation.

Physical activities can be conditionally possible, depending on properties of the activity. For example, a user may have a disability that makes short walks possible, while longer walks are impossible.

To distinguish between *probable* and *unlikely* activities, we identify activities that are *challenging* for the user. For each activity property, p, minimum (min) and maximum (max) values are used to distinguish between normal and challenging activities for user U, see Formula 11.

$$\begin{aligned} Normal(p,U) &= (min_p, max_p - d] \\ Challenge(p,U) &= (max_p - d, limit) \end{aligned} \tag{11}$$

$Normal(p,U)$ is an interval reflecting the user's previous achievements with respect to property p. For example, if p represents walking distance, max_p and min_p represent the longest and shortest distance, respectively, walked by user U. $Challenge(p,U)$ is an interval for p which represents efforts that are possible for the user, but currently beyond the user's maximum. An absolute *limit* for p can be registered by the user, and if p of an activity exceeds the limit, the activity is classified as *impossible*.

The d in $(max_p - d)$ represents a deviation from the max_p value and is used to adjust the upper boundary for normal activities. For example, if max_p is far above the average value for p, max_p may be too high to count as normal activity. Deviation d may be adapted to the user's current activity pattern by, e.g., being calculated as a function of average.

An *unlikely* activity is an activity the user has never done, has been repeatedly rejected when suggested in a nudge, or has one or more properties that are within the $Challenge(p,U)$ interval. An activity is *impossible* if capability or opportunity issues hinder it, or if at least one activity property is above the *limit*. Otherwise, it is a *probable* activity.

4.2.3 Green Transportation Nudging

As the user may have different habits when traveling between different (O,D) pairs, we identify *probable, unlikely*, and *impossible* transportation means per (O,D) pair. Walking may, e.g., be classified as unlikely for user U when going shopping, while it is possible when going to work.

Impossible transportation means are identified based on user capability and opportunity, and $impossible(A_{(O,D)},U)$ can, e.g., include i) *private car*, if the user does not have a driver's license, ii) *train*, if there are no train services for (O,D), or iii) *cycling*, if the user does not have a bicycle.

Transportation means where the user is physically active (e.g., walking or cycling), can be conditionally possible. Similarly to the approach in Section 4.2.2, an absolute *limit* for an activity property p can be registered by the user. If walking distance between O and D is above the limit, walking is impossible for (O,D).

To determine what is physically challenging for a user, a collective activity pattern covering all (O,D) pairs is used to determine how frequent physical activity is used as transportation means, and average and maximum values for distance and/or duration properties. These values determine similar intervals to the ones presented in Formula 11, and is used as a basis for classifying activities, as described in Section 4.2.2.

$Unlikely(A_{(O,D)},U)$ includes possible transportation means that U has never used, repeatedly rejected for (O,D), or, if it is a physical activity transportation means, has a property p within $Challenge(p,U)$.

4.3 Selecting Activity and Time Frame

4.3.1 General Description

To help the user reach the *ActivityGoal*, a nudge can either suggest a new activity that contributes to filling the $ActivityGap(P)$ or suggest an improvement of an expected activity (e.g., suggest a longer walk or improve a predicted transportation means).

An *unlikely* activity may be selected to challenge the user to do something new or more demanding, while a *probable* activity, representing the familiar or preferred, can be selected to make it more likely that the user accepts the nudge.

Time frame and activity are closely connected, as the time frame for a nudge determines which activities are possible to suggest. An obvious requirement is that the selected activity must be possible to do within the targeted time frame. For some nudges, the time frame is first selected, and an activity that fits the time frame is subsequently chosen. For other nudges, the order is reversed, and activity is chosen before the time frame.

To fill the $ActivityGap(P)$, the activity must take place in P, meaning that the time frame for the nudge must be within P. If a nudge is given with a time frame outside P and the nudge is accepted, the suggested activity will later be included as an expected activity in a future time period.

4.3.2 Physical Activity Nudging

The $ActivityGap(P)$ represents the number of steps that remains in period P to reach the *ActivityGoal*. To fill the gap, the user needs to be more active, and nudging will suggest additional activities to the user.

Different activities (e.g., frequent short walks or a long hiking trip) can be equally useful as long as the suggested activity is possible for the user to do. That is, if a nudge suggests an activity with certain properties p, such as distance or duration, each property must be within the user's $Normal(p,U)$ or $Challenge(p,U)$ interval.

What to nudge for also depends on the user's situation (such as available time) and preferences, and which nudges the user reacts positively to. Therefore, when selecting an activity from either of the two sets $Probable(A,U)$ and $Unlikely(A,U)$, these factors must be considered. Additionally, the principle of *variation* (described in Section 2.1) can be supported, by, over time, nudging for a variety of activities.

When selecting a time frame for a nudge, the time since the last activity and time frame for committed activities are important factors. Time frames should not overlap, and there must be a sufficiently large interval between the end of one activity and the timeframe for the next.

4.3.3 Green Transportation Nudging

While physical activity nudging can fill an $ActivityGap(P)$ by adding more activities, green transportation nudging can only reach the $ActivityGoal$ by improving the EF-value of activities, i.e., selecting a transportation means that is more environmentally friendly than what the user normally prefers. The number of travels cannot be adjusted to fill an $ActivityGap(P)$. Travels are triggered only by the user's need to change location.

A location change is detected by i) monitoring the user's activity pattern to detect regular location changes, ii) using calendar information to detect appointments that require location change, and iii) letting the user register a location change.

The goal is to nudge the user to choose transportation means so that, when period P is over, $ActivityGap(P) \leqslant 0$ (i.e., the $ActivityGoal$ is reached). A nudge should suggest a transportation means that brings a positive $ActivityGap(P)$ value closer to 0, or keeps $ActivityGap(P) \leqslant 0$.

The system must detect which (O,D) pair the user can improve, and determine which improvement to suggest. If user U has previously traveled (O,D), there exists an expectation of which transportation means the user will choose and a corresponding predicted EF-value. To improve, a transportation means with a better EF-value must be selected from either of the sets $Probable(A_{(O,D)}, U)$ or $Unlikely(A_{(O,D)}, U)$.

Available transportation means are partially ranked based on their EF-values. This means that some transportation means (e.g. walking and cycling) are equally environmentally friendly and can have the same EF-value.

5 DISCUSSION

This section discusses some observations made during the work on smart nudge design. It includes how relevant activities can be determined ahead of nudge design, to make the design process more efficient, and how a system can create plans for nudging, either as a set of individual nudges or a succession of linked nudges. This section also shows how the smart nudge design fulfills the design principles presented in Section 2.1.

5.1 Predetermining Relevant Activities

To simplify the task of choosing an activity, a set of only relevant activities (denoted $RelActivities$) can be identified. To make nudging more efficient, the content of $RelActivities$ can be determined in advance, before nudge design time. Activities that are permanently impossible for the user, are the most obvious activities to be excluded from $RelActivities$.

A nudge must include an activity that represents an improvement, or at least a status quo, with respect to user behavior. In general, this means that all activities that represent a decrease in behavior should never be nudged for and are consequently excluded from $RelActivities$.

For green transportation nudging, the partial ranking of activities makes it possible to identify activities that represent a decline in user behavior and disregard them as not relevant for nudging. For example, if the user is predominantly walking to work, a nudge can suggest walking or cycling, but will never suggest public transportation or carpooling (since this represents a decline in behavior).

For physical activity nudging, where every activity contributes to reaching the $ActivityGoal$, it may be more difficult to discard activities as not relevant. However, for a relatively active user, the system may choose never to nudge for short or very easy activities, as these may not be considered a push towards improved behavior.

5.2 Creating a Nudging Plan

The $ActivityGap(P)$, described in Section 4.1, represents a prediction of how much the user must improve to reach the $ActivityGoal$. When predicting a deficiency in user behavior, the system can set up a plan for nudging so that the user can reach the goal during period P.

A nudging plan consists of a set of nudges $\{n_1, \ldots, n_m\}$, where each nudge can be predesigned, including a tentative activity, time frame, and other nudge components. When it is time to nudge the user, the final nudge design is done, and tentative components may be replaced if the user situation at nudge design time makes it necessary or beneficial. The nudging plan may be adjusted during P as the user situation may change or the $ActivityGap(P)$ is updated and the prediction changed.

A physical activity nudging plan can be created by detecting periods, during P, when the user is available for being active, and planning a nudge for each selected time frame. The planned nudges are spread over the period, and design and presentation of a nudge are done close to the selected time frame.

A green transportation nudging plan can be created by identifying planned travels (i.e., (O,D) pairs) during *P*, where the user's transportation habits can be improved, and planning a nudge for each selected (O,D) pair.

5.3 A Sequence of Nudges

Ranking of activities can be used as a basis for designing a sequence of linked nudges, where the first nudge suggests a higher-ranked activity than the next nudge in the list. When one of the linked nudges is accepted, the following nudges in the list are discarded.

For example, when nudging for transportation means between *O* and *D*, the system can first nudge for walking, and later, if the user did not walk, issue a new nudge for taking the bus. This gives a list of linked nudges, where walking has a better EF-value compared to public transportation.

5.4 Fulfilling Nudge Design Principles

The nudge design approach presented in this paper, follows the design principles described in Section 2.1. The principles of challenge, consolidate, and progress describes how nudging should stepwise challenge the user to improve behavior. The need to *challenge* the user is supported by automatically increasing the *ActivityGoal* value as the user's behavior improves. The *consolidate* and *progress* principles are handled using the three behavioral progress states (*improved, stable, decreased*), where the *consolidate* principle is followed when the user is in the *improved* state, while the *progress* principle is used for the states *stable* and *decreased*.

The *variation* principle is supported by keeping a set of possible activities (i.e., $Possible(A,U)$) and recognizing that an activity can be selected from either of the two sets $Probable(A,U)$ and $Unlikely(A,U)$, as long as the activity represents an improvement or a status quo with respect to user behavior.

Timeliness is supported by detecting time frames when nudging is needed or can be effective for the user. For physical activity nudging, an opening in the calendar can be utilized for exercising, while for green transportation nudging an arrival time at the destination, together with the selected activity, sets a required time frame for a nudge.

Feasibility is supported through classification of activities, where impossible activities will never be nudged for, while *safety* is supported by recognizing harmful or hazardous situations as obstacles that identify an activity as potentially dangerous and classify it as impossible.

6 CONCLUSION

This paper presents a model for adaptive nudge design, that provides personalized and context-aware nudges tailored to the user's current need for a gentle push towards a desirable change in behavior. The model follows a just-in-time nudge design approach, where tailoring of nudges is based on the user's behavior, situation, and environment at the time of nudging.

The design process adapts according to the user's change in behavior, by continuously challenging the user to improve based on an adaptive activity goal, which is automatically adjusted as user behavior improves. Activity and time frame for a nudge is selected based on what is needed for the user to reach the activity goal, and what currently is possible for the user.

This paper targets the questions of *what to nudge for* and *when to nudge*. Other aspects of nudge design, such as details regarding which influence type to select and how to present the nudge are left for future work.

The model is described through a general approach to selecting activity and time frame for a nudge, followed by examples of how the proposed solution can be used in two different use cases; physical activity nudging and green transportation nudging. Future work includes applying the general approach to other use cases. Presenting practical experiments using the design model is also left for future work.

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