CONNECARE

WP4 – SELF-MANAGEMENT AND MONITORING

D4.6: RECOMMENDER SYSTEM FOR SELF-MANAGEMENT

H2020-EU.3.1: Personalised Connected Care for Complex Chronic Patients

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Abstract	This deliverable has the twofold goal of *(i)* reporting on the activities carried out to develop the Recommender System for Self-management, and *(ii)* describing the resulting software artefact. Accordingly, Section 1 motivates and gives context to the work done, Section 2 summarises the requirement collection phase, Section 3 describes the functionalities of the resulting software artefact, Section 4 presents its the software architecture, Section 5 provides technical details on the integration with the rest of the CONNECARE ecosystem, Section 6 discusses evaluation of the tool, Section 7 looks forward to future iterative improvement steps, and, finally, Section 8 concludes the document.

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Executive Summary

This document describes the research and development activity carried out to deploy the Recommender System (RS, henceforth) software artefact, produced to accomplish **Task 4.6 “Recommender System for Self-management”**, and contributing to achieve also Task 4.1: “Design and development of the CONNECARE personalized self-management system”, Task 4.2 “Basic Monitoring” and Task 4.3: “Advanced Monitoring”. Also, the co-design process adopted in order to maximize likelihood of readily adoption in clinical sites is documented here, in particular as regards requirements collection which involved all the clinical sites, hence all the clinical partners: IRBLL and ASSUTA, especially, validated the system through both volunteers and actual patients. Finally, the RS has been developed in collaboration with the team responsible for the design of the CONNECARE Self-Management System, SMS, (deliverable D4.7, that will be delivered at M45, December 2019), so as to be readily and effectively integrated. Integration has been made together with researchers and developers from EURECAT.

This deliverable directly contributes to the specific objectives of WP4 regarding the “*research and develop the recommendation system for giving feedback to the patient*” and to the general goal of the project of “*empower patients to take care of themselves, through a self-management approach based on recommendations and suggestions*” (objective OBJ5 defined in the DoA).

The table below summarizes the suggested readings and their role with respect to the present document.

Table 1 List of related deliverables, either preparatory or complementary.

Number	Title	Description
D2.5	PDSA process and final design of the CONNECARE system	The current document provides a complete view of the Plan Do Study Act (PDSA) methodology used through-out the project, including the main objectives, methods and outcomes for each cycle and how this iterative strategy allowed to shape the CONNECARE system. Moreover, it provides a summary of the final design of the system, with a focus on the functional and non-functional requirements that fostered the development and improvement of the system and how these requirements were tackled.
D4.1	First self-management system	This document describes the first version of the self-management system (SMS) as a study release to be used during the clinical studies by the patients. The document presents the architecture, development phases and deployment of the system, and the requirements requested by the patients and professionals.
D4.2	Basic monitoring tools	This deliverable illustrates the tools (services) that have been investigated and developed to be part of the SMS in order to perform

		monitoring of basic activities. The underlying model, that will be common also for the advanced and assistive tools, has been first introduced in order to give the big picture of how monitoring is performed in CONNECARE. Each implemented service has been then described at a high-level, whereas in the annexes technical details of each are given.
D4.3	Advanced monitoring tools	This deliverable illustrates the tools (services) that have been investigated and developed to be part of the SMS in order to perform monitoring of advanced activities. The underlying model, common for the basic tools, has been already introduced in D4.2. Each implemented service has been then described at a high-level, whereas in the annexes technical details of each are given.
D4.5	Quality of Life Assessment System	This deliverable presents the research that has been made by EURECAT, in collaboration with ASSUTA and UMCG, to study a solution for automatically assessing quality of life. In particular, quality of life has been meant in this study as the patient's overall status (through the EQ-5D-5L questionnaire), her/his perceived level of anxiety/depressions (through the HADS questionnaires), together with the data about sleep from a commercial wristband.

1 Introduction

Patient **self-management** plays a central role in the P4 medicine paradigm [2], as it has a beneficial impact on both physical and psychological health status [3]. From a technological standpoint, *personalization*, *adaptation*, and *scalability* are key properties to leverage when designing and developing software solutions promoting self-management through, for instance, **patient empowerment** [4].

One way of empowering patient so as to let them self-manage not only their disease but also their day-to-day life is to let them be **aware** of their healthy or unhealthy habits with the goal of, respectively, encourage them or not. For instance, a common strategy regarding physical activity practicing is to provide regular reminders based on objectively measured levels of **adherence** [5]. This is true for both activities of healthy subjects and prescriptions to patients suffering of some chronic condition [6].

In CONNECARE, the basic and advanced monitoring tools enable continuous and real-time tracking of patients' physical activities such as walking or performing simple activities of different magnitude by relying on a commercial wristband. As documented in D4.2 and D4.3, the Fitbit wristband has been adopted in the clinical studies to monitor the physical- and sleeping-activity. Regarding the physical activity, Fitbit recognizes three levels of activity (light, moderate, vigorous) as well as sedentary. In turn, this enable an automated software system to provide reminders, nudges, and similar interactions to patients based on the monitored activities, with the goal of keeping patient engagement, improve adherence to professionals' prescriptions (e.g. in case of pre/re-habilitation before/after surgery), and in general to improve and maintain healthy habits.

This is exactly the purpose of the Recommender System that has been studied, developed, and adopted in CONNECARE and is presented in the remainder of the document.

1.1 Motivation

In [3], self-management is interpreted as the "day-to-day tasks an individual must undertake to control or reduce the impact of disease on physical status." For instance, many studies show that engaging in healthy diet, exercise, or similar self-management habits has physical benefits in terms of fewer symptoms, better functional capability, and fewer complications in various diseases (e.g. asthma or chronic obstructive pulmonary disease [14], and heart failure [15]). There, evidence of a *bidirectional association between wellbeing and adherence to self-management regimes is provided*: those who practice self-management report improved wellbeing [16].

Accordingly, Clark et al. [3] identified *maintaining exercises and activity levels* [17] *as well as monitoring physical indicators* [18] *among the main features that positively impact management and improvement of chronic diseases* in older adults. Not by chance, these functionalities are the focus of the CONNECARE RS described in Section 3, and the main source of **personalization** and **context awareness** for the motivational messages sent to patients.

1.2 GOALS

The literature on self-management also recognizes the crucial role played by mobile phones and other devices as enabler technologies for effective patient-centred care and patient empowerment. In fact, mobile apps are increasingly recognized by policymakers as a medium for supporting self-management of long-term conditions [19]. Huckvale et al., for instance, confirmed this trend with their systematic literature review for the assessment of apps for the management of asthma [20].

The Recommender System presented in next section is positioned in this context, as it relies on a mobile app to deliver recommendations to patients (the CONNECARE SMS, which delivers many other functionalities detailed in D4.2 and D4.3), and on a smart wristband to monitor activities so as to infer adherence (the Fitbit has been selected by the clinicians in all the sites). The goal of the RS is to deliver to patients enrolled in the CONNECARE studies personalised motivational messages ("recommendations", henceforth) aimed at (i) keeping patient engagement in self-management habits high, (ii) make them aware of their adherence and performance with respect to clinical prescriptions, and (iii) improve their adherence to prescriptions as well as general healthy habits.

The value-added of the RS is the delivering to patients of real-time and up-to-date information regarding their adherence to prescriptions, while also personalising the information given so as to promote engagement. Current commercial solutions, in fact, aim to keep patients autonomous by providing them with wearable, non-intrusive devices (e.g., wristbands and medical devices), paired with proprietary smartphone apps (for instance, the FitBit devices with its companion smartphone app). Nevertheless, recommendations are predefined by providers and usually cannot be personalized. On the contrary, *clinicians interested in monitoring activities, health-status, and possibly habits, prefer to prescribe the goals to be achieved by each patient (e.g., in terms of number of steps and minutes of activities per day) and expect the system to generate tailored recommendations accordingly*---as CONNECARE RS does.

1.3 CONTEXT

The Recommender System (RS) has been realised as one of the many services (micro-services, actually) altogether constituting the SMS ecosystem, as depicted in Figure 1.

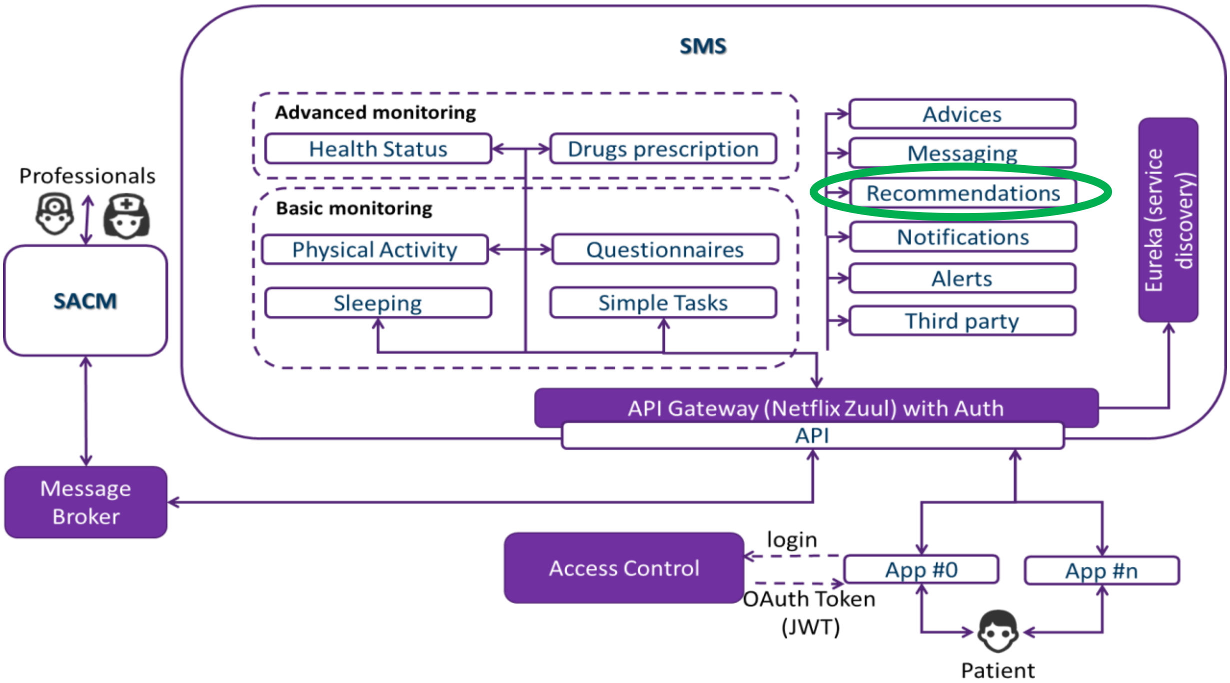

Figure 1 Overview of the SMS eco-system of microservices, there including the RS.

As such, the RS is a RESTful web service which does not have any frontend, nor as a web application, nor in the CONNECARE SMS. In fact, although delivery of messages to the patients obviously happens via the SMS, the RS recommendations are handled as a special kind of advices, marked as "automatic" to let the patient be aware that they are coming from an automatic system rather than from a clinician, and displayed in a dedicated CONNECARE SMS screen complementing the one about the rest of the advices, as depicted in Figure 2.

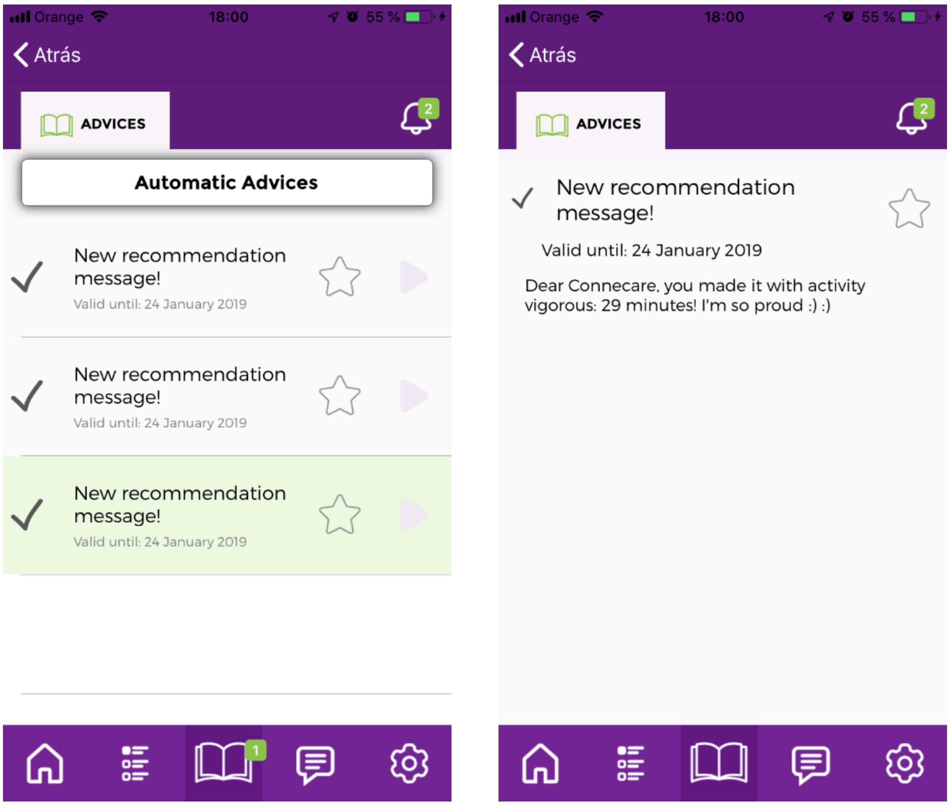

Figure 2 Recommendation messages sent by the RS to SMS, the visualised to patient through the SMS app.

2 Requirements

Functional requirements of the RS have been defined by involving all the clinical partners in an **iterative co-design process** (i) in which a set of high-level requirements informed a first prototype version of the software artefact, (ii) which was then exploited to generate exemplary messages, (iii) that were shown to clinicians so as to gather corrections and improvements in the form of refined requirements, triggering the co-design process again.

Non-functional and technical requirements have been agreed upon with all the technical partners so as to align to the general technological stack adopted by the other components of the CONNECARE system.

2.1 FUNCTIONAL REQUIREMENTS

The gathered requirements are not only about the content and format of the messages to be delivered, but also cover the process of delivery: *when* to deliver *which* messages, *how often*, whether such process could be modulated at run-time, and similar considerations. We can conveniently categorize requirements along the following dimensions:

- **Message content**: *which information the recommendation should deliver to patients*. For instance, the percentage of prescribed activity successfully completed or the amount yet missing to achievement of the prescribed goal.
- **Message format**: the *language* to encode the message. As CONNECARE spans multiple clinical sites in different countries across Europe, multiple languages have to be supported (i.e., the RS supports English, Catalan, Spanish, Dutch, Hebrew, and Russian).
- **Delivery strategy**: *how to choose what information to put in the message*. This dimension is directly related to *personalization and context-awareness* of the recommendation, as these sort of requirements establish the kind of recommendation based on the adherence of the patient to the prescriptions monitored by CONNECARE basic and advanced monitoring system.
- **Delivery policy**: *when to send recommendations, at what pace*. This dimension may seem to bear secondary relevance with respect to, for instance, the message content, but as the literature on motivational messages suggests choosing the timing and pace of delivery is fundamental to keep engagement high. A poor choice of these settings could in fact be counter-productive, resulting in patients annoyed by the system and ultimately stopping using it (e.g. by disabling push notifications).

Requirements gathered about the message content are:

a) The message should contain information referring to the patient situation, such as how far the prescribed goal is, how much activity has been done, time left, etc. In particular, the first topic selected by clinicians across sites for the recommendations has been the **physical activities** domain, hence daily prescriptions regarding the number of steps to do, the amount of light, moderate, and vigorous activity (in minutes) to do, as well as the amount of sedentary activity to limit to (again, in minutes).

b) The message may contain personal information, such as the patient name, so as to improve engagement by “feeling personal”.
c) The message should adapt its content to the kind of recommendation to deliver; for instance, if the prescribed goal has not been achieved, the message should convey some form of complaint, whereas if goal achievement is near the message should be more like an encouragement.

A shared spreadsheet has been circulated amongst clinicians to gather exemplary sentences, then the content has been analyzed and factorized to some common, recurring patterns---e.g. salutation, reference to context, motivation, etc., see Section 3.4.

Requirements gathered about the message format are:

a) Messages should be delivered in the preferred language set by the patient in the CONNECARE SMS, hence the following language translations should be supported: English, Catalan, Spanish, Dutch, Hebrew, Russian.
b) Also, messages should be simple text and not contain any other media, so as to be easily visualized on any kind of device.

Another shared spreadsheet has been circulated amongst partners so as to gather accurate translations of each word / sentence, as well as to check translations from a grammar standpoint (e.g. male / female, pronouns, verbs, etc.) as each different language has its own peculiar rules complicating translations.

Requirements gathered about the delivery strategy are:

a) Recommendations sent to patients should be based on the **adherence** of the patient to the active prescription, that is, a *quantitative measure of how compliant the patient is to the prescription goals* set by the clinician. For instance, percentage of completion can be a measure of adherence.
b) Adherence of patients to prescriptions should be ideally computed in real-time, as soon as data from CONNECARE basic monitoring and advanced monitoring tools is fetched by the RS from the SMS.

Details about how adherence is computed and how recommendations messages are linked to the computed adherence value are described in Section 3.1-3.4.

Requirements gathered about the delivery policy are:

a) Recommendations should be sent on a daily basis, as prescription goals for physical activities are set on a daily basis.
b) Messages about goal achievement should be sent *right away*, ideally in real-time as soon as the goal is achieved, hence the prescribed activity completed, as a way to readily award patient about success, and motivate them to continue to keep adherence high.

c) Messages about missed goals should be sent either at the end of day or early on the day after, so as to inform at the earliest time possible the patient about her/his non-compliant behavior, and let her/him adjust her/his activities accordingly.
d) "Motivational" messages trying to nudge the patient towards goal achievement when it is near, or warning them about potential non-compliant behavior when goal achievement is still far away, should be sent during the day, either upon need (according to real-time monitored situation of the patient) or at fixed time points.
e) In any case, recommendations messages should be sent at a maximum rate of 3-4 a day, as according to literature sending too many messages is counter-productive, also taking into considerations that patients may be already receiving other forms of notifications from the CONNECARE SMS on their smartphones / tablets.

2.2 NON-FUNCTIONAL AND TECHNICAL REQUIREMENTS

As regards requirements related to non-functional aspects, such as robustness of the software, licensing, technological stack adopted, and similar, the RS has been developed in compliance with the development process adopted by all CONNECARE components and with state-of-art technologies and standards. As such:

- The RS is a **RESTful web service** interacting with the SMS backend via HTTP methods and by exchanging JSON data. In this way, interoperability with other software component is maximized as the HTTP protocol and JSON format are agnostic with respect to, for instance, the development platform and programming language used to implement the service application logic. Another consequence of this is that any other service willing to exploit RS functionalities, or any service the RS should be hooked up to (e.g. in place of the SMS) can be easily integrated as long as they can perform / reply to HTTP requests---which is something every modern development language and platform can do. For instance, the recommendation messages could be easily shown also on the professionals' workstation through a web application interacting with the RS, if desired, so as to monitor the RS behaviour.
- All the third-party libraries used for the development of the RS are **open source** and have permissive licenses open to commercial exploitation. The RS source code itself will be open-sourced at the end of the project.
- The RS has some flexibility regarding re-configuration at run-time, that is, without the need to stop the service. For instance, the pace at which recommendations are sent and the adherence thresholds for sending different messages can be configured through HTTP calls with no need to restart the service (hence no downtime). See Section 4 for further details.
- The RS is deployed through a Docker image and a correspondent Docker configuration (docker-compose file), which ensures that the executing platform has all the needed software stack to properly run the service.

3 Functionalities

At the higher level of abstraction, the RS delivers one single functionality: *the automatic crafting and delivery of personalized motivational messages tailored to the specific patient situation* in terms of compliance to clinicians' prescriptions. This is in fact the only "visible" functionality from the perspective of the users (the patient and her/his carers) and the clinical staff, as results in the reception of a simple text message in a dedicated screen of the CONNECARE SMS on patients'/carers' smartphones or tablets, as shown in Figure 3.

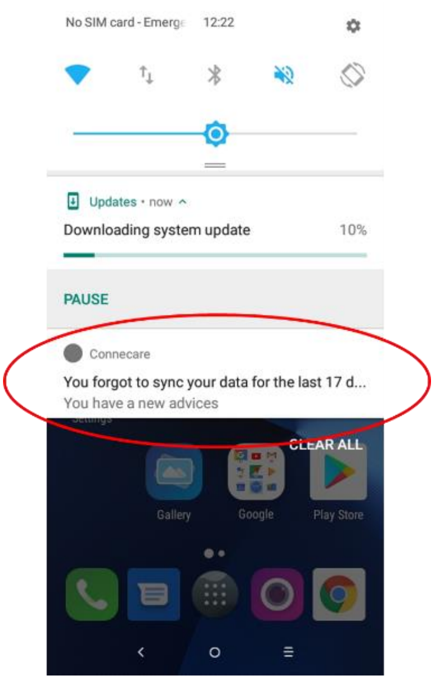

Figure 3 Example of push notification received by patients on their smartphones/tablets from the RS.

Nevertheless, this single high-level functionality is delivered through a set of sub-functionalities which are currently transparent to the clinicians and the patients, but on the one hand are vital for the RS work cycle, and on the other hand could be easily exposed likewise the delivered textual recommendations, if desired (see Section 8). These functionalities are:

A. Computation of the daily adherence of the patient
B. Computation of the adherence profile of the patient
C. Computation of the type of recommendation given the adherence, or the adherence profile
D. Personalization of the text message through natural language generation (NLG)
E. Translation of the text message

3.1 DAILY ADHERENCE

Functionality A enables the RS to establish whether the patient is on track to achieve the prescription goal for the current day. Adherence A is calculated as a percentage of the amount of activity fullfilled against the prescribed goal:

$$A = \frac{\sum_1^n f_i}{g} * 100, \qquad n \in \mathbb{N}$$

where f_i is a *fulfillment*, that is, the amount of activity done by a patient at a certain point in time and with respect to a certain measurable metric (e.g. number of steps, minutes of light activity), and g is the goal, that is, the amount of activity prescribed by a clinician to be done within a certain deadline (i.e. until the end of the day) and with respect to the aforementioned measurable metric. This measure of adherence is not effectively usable as is, since it does not take into account the time elapsed from start of the prescription (in current deployment, ideally at the start of each day, hence assumed to be at 8 am), nor the time left until the deadline set by the clinician for achieving the goal (in current deployment, ideally at then end of each day, hence assumed to be at 10 pm). Thus, for instance, if adherence is low but we are in the morning of a daily prescription, there is no justified risk of missing the goal, yet. Instead, if adherence is low and the end of the day is approaching a recommendation should be sent to warn the patient about potential non-compliance to the prescription.

It is worth clarifying here that the definitions above are the most general definitions enabling great flexibility and adaptability of the RS to different prescriptions. Nevertheless, the version of the RS released in CONNECARE production environment makes use of daily prescriptions solely, that is, prescriptions which are repeated day after day for a period of time set by the clinicians through the SACM and whose goals are set for each day. In other words, all the prescriptions considered by the RS in its current version compute adherence on a daily basis.

Back to the formulas, the actual adherence $\mathcal{A}$ is calculated as the difference between adherence A and optimal adherence $\hat{A}$:

$$\mathcal{A} = A - \hat{A}$$

Where the optimal adherence is computed so as to answer question *"how much of the activity should the patient have performed by now to achieve the goal at deadline?"*, as follows:

$$\hat{A} = \frac{(\frac{g}{t_a} * t_e)}{g} * 100$$

where t_a is the time available to achieve the goal (from reception of the prescription to its deadline), and t_e is the time elapsed since reception of the prescription. Again, this is the most general implementation of the concept which lends itself to be easily adapted to more complex prescriptions than those currently in use in the RS in CONNECARE. It is worth noting that term g can be reduced in the above equation, thus optimal adherence ends up being simply a percentage of elapsed time over available time:

$$\hat{A} = \frac{(\frac{g}{t_a} * t_e)}{g} * 100 = \cancel{g} * \frac{1}{t_a} * t_e * \frac{1}{\cancel{g}} * 100 = \frac{t_e}{t_a} * 100$$

Indeed, for a patient to achieve a goal it is sufficient to do t_a activity for each "unit of time" (that in the case of CONNECARE is an hour, but that more generically could be a day for weekly or monthly deadlines, etc.) since reception of the prescription until deadline.

As a consequence of the equations shown, adherence $\mathcal{A}$ is positive when the patient is doing better than optimal adherence, and negative when the patient is doing worst---also considering time left to achieve the goal. Notice that using the simple difference instead of, e.g., a ratio, provides useful information for the contextualization of recommendation messages in terms of, for instance, how many steps below/above the minimum required to achieve the goal the patient is doing—straightforwardly calculated as $\mathcal{A} * g$.

As a simple explanatory example, let us assume that a patient has done 4.000 steps at noon, given a prescription of 10.000 steps per day. The optimal adherence, considering a day as 8 AM – 10 PM, would lead to 10.000 / 14 * 4 = 2.857 steps (rounded), hence adherence of the patient is good, and no recommendation message would be sent. Conversely, if the patient would have done the same amount of steps (4.000) at 6 PM, the situation would change: optimal adherence would lead to 7.143 steps (10.000 / 14 * 10), hence adherence of the patient would not be good, and a motivational or warning recommendation message would be sent to encourage the patient towards achievement of prescription goal.

3.2 ADHERENCE PROFILE

Functionality B enables the RS to relate daily adherence with prolonged time periods, so as to assess how adherence fluctuates during time. The RS relies on two counters, one for the number of consecutive days in which the patients achieved the goal (*winstreak*), C^+, and one for the number of consecutive days in which the patients did not achieve the goal (*losestreak*), C^-. Any time the patient moves from achieving to not achieving the goal, the C^+ is reset to 0. The same with C^- when moving from not achieving to achieving.

Early in the morning, the RS checks if the day before the goal has been achieved or not, and it updates C^+ and C^-, accordingly:

$$\begin{cases} \sum_{i}^{today} C_i^+ \text{, in the case the patient achieved the goal, 0 otherwise} \\ \sum_{i}^{today} C_i^- \text{, in the case the patient did not achieve the goal, 0 otherwise} \end{cases}$$

Depending on the number of days that the patient is achieving / not achieving the goal, the message will be more or less effective. The more the number of days s/he is not achieving, the stronger the message to push the patient to improve. The more the number of days s/he is achieving, the stronger the message to compliment the patient and to push her/him to doing better and better.

3.3 Recommendation type

Functionality C exploits functionalities A and B to define the kind of recommendation message to craft, in turn influencing the content of the messages, depending on the adherence or adherence profile of the patient.

As far as the adherence is concerned, 4 kinds of recommendation messages have been designed---ordered by decreasingly good compliance:

- **Award**. The kind of message sent as soon as the patient achieves the prescribed goal. Ideally, this condition is checked in real-time, hence the recommendation delivered as soon as the goal is achieved. However, due to technical limitations, the check and the delivery are performed periodically as configured by the delivery policy (see Section 4).
- **Motivational**. The kind of message sent if $\mathcal{A}$ is less than -25%, meaning that the patient is slightly behind optimal adherence, hence will need some improvement to reach the daily goal. The adherence is checked, hence the message sent, at fixed time points configured by the delivery policy (see Section 4).
- **Warning**. The kind of message sent if $\mathcal{A}$ is more than -25%, meaning that the patient is sensibly behind optimal adherence, hence will need serious improvement to reach the daily goal. The adherence is checked, hence the message sent, at fixed time points configured by the delivery policy (see Section 4).
- **Alert**. The kind of message sent as soon as the patient misses the prescribed goal. The check, hence the delivery, is performed at a fixed time point configured by the delivery policy (see Section 4).

As far the adherence profile is concerned, instead, three kind of messages have been designed:

- **Winstreak**. Message awarding the patient with the length of the winstreak, that is, the number of consecutive days of reaching the goal. This message is based on counter C^+ described above.

- **Losestreak**. Message alerting the patient with the length of the losestreak, that is, the number of consecutive days of not reaching the prescription goal. This message is based on counter C^- described above.
- **Synch**. In the case that the patient is not synchronizing the device and the data are not coming to the overall SMS backend and, thus, to the RS (for instance, if the patient does not open the CONNECARE SMS app for a while). The RS, before sending messages of type B (that is based on adherence profile), checks first if they relate to yesterday or not: if not, it verifies the date and calculates the number of days without receiving data. Then, a recommendation to remind the patient to synchronize the device is sent. This message may be also customized and sent only after a given number of days s/he is not synchronizing (e.g., after 3 days).

3.4 PERSONALIZATION

Functionality D enables the RS to craft a sentence in natural language delivering the kind of recommendation established as discussed in Section 3.3, whose text not merely a "neutral" sentence easily fitting anyone, but is instead *tailored* to the patient information (e.g. name), and to her/his condition with respect to the prescription for which the recommendation is being generated. This could mean, for instance, referring to the prescribed activity (e.g. "steps", "vigorous activity", etc.), to the time left to completion (e.g. "deadline is approaching"), and to the actual adherence (e.g. "1000 steps left").

Delivering this kind of functionality is far from trivial in the specific case of CONNECARE: on the one hand, automatic sentence generation requires exploitation of Natural Language Processing (NLG) techniques and technologies whose most performant instances are mostly proprietary software, hence do not cope well with the non-functional requirements described in Section 2.2, on the other hand the requirements about message format explicitly mandate for localization in each patient preferred language, which further hinders usage of NLG software libraries or services as they are typically provided for the English language (hence grammar) whereas each language has its own grammar rules for building sentences. Given these considerations, two alternatives have been considered to still deliver some form of personalization in face of difficulties:

- either rely on NLG technologies built for English, then translate the generated sentences post-hoc by using translation services such as Google translate
- come up with a method to craft sentences by composing independent pieces which could be translated on their own before composition

The former choice would have been the easiest from a software development perspective, as it allows to re-use existing and well established libraries and services for both NLG and translation. However, some testing to check the quality of translations together with clinical partners from across the different CONNECARE sites revealed inadequacy of the translation output for some languages, mostly Hebrew and Russian. As having clear and easy to understand messages is even more relevant if elderly people are involved, automatic translation services has been quickly dismissed. It is also worth noting here that no so many web services offer Hebrew translations.

For the above reasons, it was decided to pursue the second path and conceive a way to craft sentences by composing independent pieces of text. Describing in details the motivations and design choices leasing to the final result is beyond the scope of this document, and currently subject of publication in scientific conferences and journals, nevertheless a glimpse of the process is due to let the reader appreciate the work done.

A **sentence template** has been defined for each kind of recommendation, meant to define the *structural shape* of the final sentence to deliver as recommendation message in terms of a set of ordered **tokens** suitable to be translated in isolation. The typical sentence template is akin to what follows:

`[Greeting] [Filler] [Assessment] [Call to action] [Argument]`

where each token may include **context variables**, which are *placeholders for run-time values* depending on the specific patient situation, hence ultimately enable personalization. For instance, the `[Assessment]` token is meant to let the patient receiving the recommendation be aware of her/his current situation regarding the prescription, hence typically refers to the prescribed activity as follows:

`[Assessment] = "doing well with" + {$pre.metric}, {$pre.goal}, {$post.level}`

where text between double quotes is not subject to change or replacement as it is readily available translated in each of CONNECARE languages, and simply fetched at run-time depending on the patient language preferences, whereas every token within curly braces is a context variable which is replaced at run-time with the corresponding value as fetched from the prescription or the fulfillment data stored in the SMS. For instance, in the example above: `{$pre.metric}` refers to the prescription metric (e.g. “steps”), `{$pre.goal}` refers to the prescription goal (e.g. “10,000”), and `{$post.level}` refers to the level of activity currently performed (e.g. “7,000”). Hence, the `[Assessment]` token above would read at run-time as, for instance:

`doing well with steps: 7,000 out of 10,000`

Going through all the possible context variables is beyond the scope of the document, but briefly describing the tokens is due to let the reader appreciate the expressiveness and personalization possibilities opened up by the conceived method:

- `[Greeting]` is the salutation that generally starts the message, usually featuring the patient name or its surname (preceded by a salutation particle, such as “Mr.”). Such a salutation is adjusted to match the time of the day at which the recommendation is delivered (e.g. “Good afternoon” between noon and 6 pm).

- `[Filler]` is a short sentence, usually in form of a question, which is generally applicable and serves as a way to show empathy and keep engagement, by showing interest in the patient mood (e.g. “how is it going?”).
- `[Assessment]` is a short sentence meant to assess the state of patient activity with respect to the prescribed goal in a qualitative way. As it closely depends on adherence, it can be positive (e.g. “goal is quite close”) or negative (“goal is still far away”). Also, it usually features context variables meant to quantify distance to goal achievement, as exemplified above. This token is optional as it is not used in Awards and Alerts recommendations.
- `[Call to action]` is a short sentence also closely depending on the recommendation type (hence which can be positive or negative) specifically meant at delivering some form of encouragement (e.g. “come on”, “don’t give up”), warning (e.g. “watch out”), or in general any support worth to show the patient some empathy (e.g. “congratulations” in case of goal achievement).
- `[Argument]` is an optional piece of text that serves to motivate why the patient is receiving the recommendation (e.g. “deadline is approaching” in case of a Warning recommendation).

All these “virtual” elements are associated to actual text in a set of configuration files, which

- map the recommendation type (Award, Motivational, Warning, Alert) to a pool of sentence templates (mostly one, but more can be created by arranging the order of the tokens in different ways), and
- each token in a sentence template to a set of text pieces, which can be used interchangeably (hence are used to deliver some diversity in the recommendation messages received by patients)
- and each of these elements in each of the languages available in CONNECARE (English, Spanish, Catalan, Dutch, Hebrew, Russian)

To expand or modify the sentences delivered by the RS it is sufficient to modify these configuration files.

As an example, here follow a list of text messages which have been randomly sampled from the logs of the Recommender System, thus that have been actually delivered to patients enrolled in CONNECARE case studies (actual message and English translation given):

- “Hola Antoni. Activitat 'passos': s'ha perdut l'objectiu diari, ho sento.” (Hi Antoni. Activity 'steps': daily goal has been missed, I’m sorry :()
- “Hola Antonia. Activitat 'passos': l'objectiu diari no es va aconseguir, és una llàstima.” (Hello Antonia. Activity 'steps': the daily goal was not achieved, it is a pity :()
- “Hola Carlos. Actividad 'ligera': felicitaciones por lograr el objetivo diario.” (Hello Carlos. 'Lightweight' activity: congratulations for achieving the daily objective :))

- “Bunenas tardes Carlos. Actividad 'pasos': la meta diaria está a pocos pasos de distancia, intentemos conseguirla.” (Good afternoon Carlos. Activity 'steps': the daily goal is a few steps away, let’s try to achieve it!)
- “доброе утро пациент. деятельность 'сидячая': мои комплименты за достижения ежедневной цели.” (Good morning patient. Activity 'sedentary': my compliments for achieving the daily goal :))
- “אחר מטופל. 'צעדים' פעילות: המטרה את והשג פעולה נקוט ,שלך היומית המטרה את להשיג אפשרי עדיין טובים הצהריים” (Dear patient, it is still possible to achieve your daily goal, take action and achieve ‘steps’ activity!)

3.5 TRANSLATION

Functionality E enables the RS to deliver to the SMS backend recommendation messages which are already translated in the language of choice of the patient target of the recommendation (set by her/him through the CONNECARE SMS).

As already described in previous section for functionality D, configuration files handle localization of textual content in each language, there including right-to-left writing needed for Hebrew.

An exemplary translation sheet resembling the one actually used amongst clinical partners is available for inspection at the following URL:

https://docs.google.com/spreadsheets/d/1Gmdk9npKCpU8k4QW9A_dQT9J1IwEdx1_CvpSiDt6nww/edit?usp=sharing

4 Architecture

The RS is a **RESTful web service** realized in Java and interacting with the CONNECARE SMS through HTTP methods exchanging JSON documents. As such, it does not deliver any frontend, as the recommendation messages it generates are delivered to the patients through the CONNECARE SMS installed in their smartphones/tablets.

The RS delivers its functionalities by letting four main components cooperate, as depicted in Figure 4:

- **Monitoring**. The RS module in charge of fetching the data the RS needs to compute recommendation messages. It interacts with the CONNECARE SMS that exploits a stack of monitoring services, for instance, relying on a smart wristband to monitor physical activity (i.e. number of steps, duration of light / moderate / vigorous / sedentary activity). More details in Section 5.
- **Adherence**. The module computing the adherence of patients to prescriptions as described in Sections 3.1-3.2.
- **NLG**. The module composing the personalized text messages to be sent to the patient app through SMS messaging services, tailored to their context of performance (e.g. remaining steps towards goals) and linguistic preference as described in Sections 3.4-3.5.
- **RS engine**. The module orchestrating others according to a dynamically configurable **policy** dictating whether and when to send the recommendations featuring motivational messages to patients, and a **strategy** dictating what to put in messages (see below).

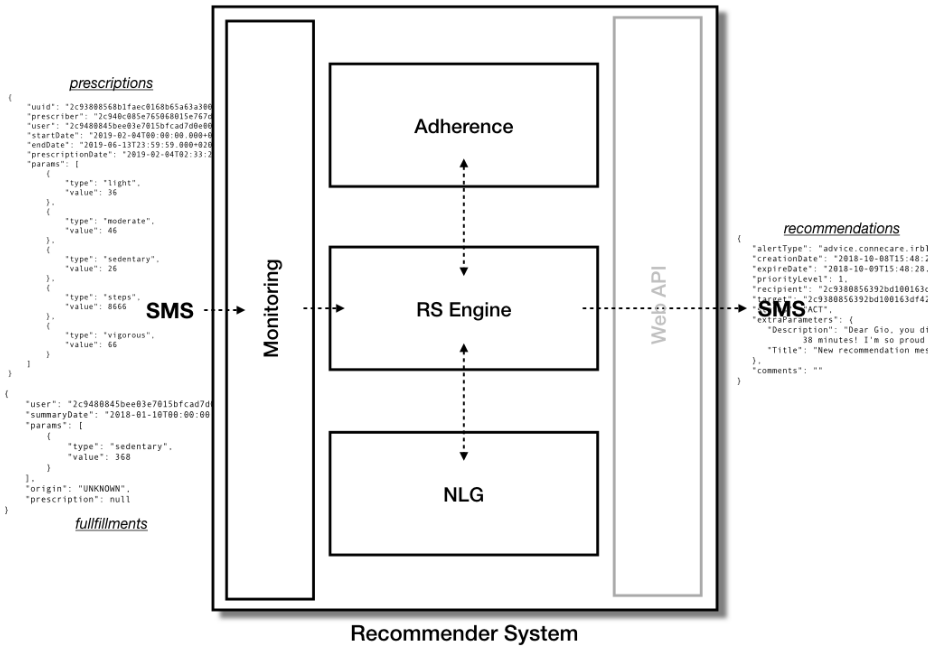

Figure 4 The Recommender System inner architecture.

In particular, the flow of end-to-end interactions, there including patients and clinicians, is as follows:

1. a clinician prescribes some physical activities to a patient by using the SACM, that dispatches the prescription to the SMS which shows it to the patient
2. the patient (possibly, partially) performs the prescribed activities, which are automatically monitored by the SMS monitoring services through the smart wristband connected to it
3. the SMS then informs the RS engine about activity fulfillments, which are used to feed the adherence module to compute the adherence of the patient
4. next, the RS engine triggers the NLG module to craft the sentence featured in the motivational message directed to the patient, based on contextual data (e.g. adherence) and linguistic preference (set through the app)
5. finally, the RS engine sends the recommendation featuring the personalized motivational message to the SMS, which shows it to the patient

Interactions with the SMS are better described in Section 5. Instead, the interactions just described between RS inner modules are instrumented by the working logic of the RS, depicted in Figure 5:

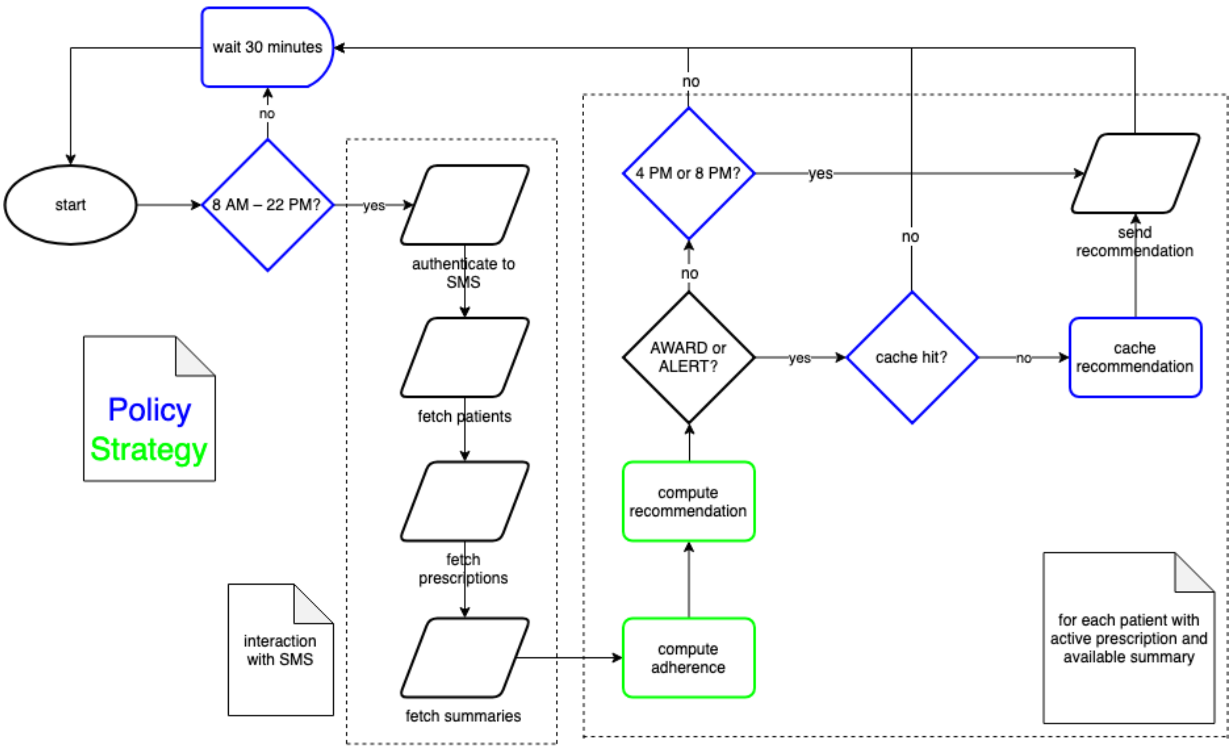

Figure 5 Recommender System application logic.

1. every time the policy dictates so (e.g. between 8 am and 10 pm), the RS engine “wakes up” and starts fetching data from the SMS (after authentication is successful), in particular

   a. the list of patients in each tenant (Assuta, IRBLL, UMCG, IDIBAPS)
   b. the physical activity prescriptions associated to each patient (only one active per day)
   c. the (possibly, partial) fulfillments of those prescriptions available to date (and time)
2. based on these data, adherence of each patient is computed, and recommendations generated accordingly, as dictated by the strategy (e.g. adherence thresholds)
3. then, the RS engine decides whether to actually send the recommendation to each patient depending on policy configurations

As regards step §1, the policy currently supports definition of a "daytime" when the RS is expected to be active, as well as a frequency of operation defining how often the RS checks whether new fulfillments are available (e.g. every 30 minutes)—to update adherence of patients. Underlying this pro-active behaviour there lies a legacy requirement: the SMS is not currently pro-actively sending data to the RS, hence the latter must pro-actively check for updates.

As regards step §3, the policy object also allows system administrators to define a caching policy on recommendations, meant to avoid spamming patients with too many messages (e.g. do not send warning if already sent), as well as the preferred times for sending motivational and engagement messages to patients who have not yet achieved the goals assigned by their prescription (e.g. 4 and 8 pm).

Explicit modelling of these strategy and policy concepts allow great flexibility and easy configuration of the RS, even at run-time---that is, with no need to stop the service.

5 Integration

The Recommender System has been fully integrated with the SMS and, thus, the CONNECARE platform and run in production environment from April 2019. Being a RESTful web service, integration means that the RS fetches the data it needs to work (e.g. patients' prescriptions and their daily activities) from the SMS HTTP endpoints and therein publishes data produced (the recommendation messages), too. The data subject of the analysis in Section 6 has thus been generated from production data, belonging to real patients enrolled in the CONNECARE program.

Interaction with the SMS proceeds as follows, as depicted in Figure 6:

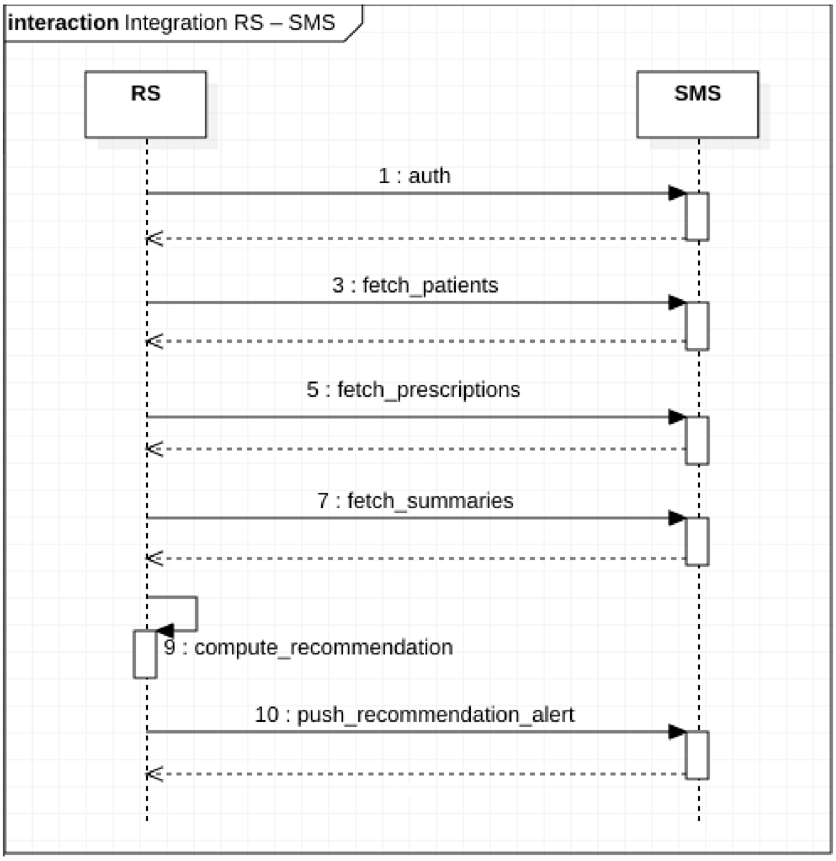

Figure 6 Interaction schema for RS - SMS integration.

1. When specified by the policy, the RS "wakes up" and authenticates through the SMS by means of credentials safely stored as Docker secrets[1] and getting back a JWT token[2] to be included in subsequent HTTP calls

[1] https://docs.docker.com/engine/swarm/secrets/

[2] https://jwt.io

2. If authentication is successful, the RS iterates over the list of tenants (stored in a configuration file, which can also be modified at run-time) to get patient data for each tenant. Among data there is the *name* and *surname* of the patient, *sex*, and preferred *language*, all useful for personalization.
3. If fetching list of patient with their data is successful, the RS then gets the **active prescription** for each of the patients (in turn, in each tenant). It is worth noting that each patient has at most one active prescription at a time, and they are all daily goals. The active prescription completely describes the prescribed goal, as depicted in Figure 7. For instance, the precise numeric values for the set of physical activities to be performed is specified.


```
{
    "uuid": "2c93808568b1faec0168b65a63a30030",
    "prescriber": "2c940c085e765068015e767d84980080",
    "user": "2c9480845bee03e7015bfcad7d0e0011",
    "startDate": "2019-02-04T00:00:00.000+0200",
    "endDate": "2019-06-13T23:59:59.000+0200",
    "prescriptionDate": "2019-02-04T02:33:23.615+0000",
    "params": [
        {
            "type": "light",
            "value": 36
        },
        {
            "type": "moderate",
            "value": 46
        },
        {
            "type": "sedentary",
            "value": 26
        },
        {
            "type": "steps",
            "value": 8666
        },
        {
            "type": "vigorous",
            "value": 66
        }
    ]
}
```


Figure 7 Example of prescription.

4. The RS then periodically, as specified by the delivery policy, fetches the actual state of fulfillment of each prescription (hence, for each patient, in each tenant), and computes (or updates) the corresponding adherence. The fulfillment ("summary" in SMS terminology) is similar to the prescription above, but contains the current level of activity performed by the patient as known by the SMS.
5. The RS then computes recommendations as described in Sections 3.3-3.4. In particular, depending on the adherence the NLG module is triggered to craft a personalized sentence.

6. Finally, if the policy establishes to do so, the RS publishes the recommendation messages to the dedicated SMS HTTP endpoint, which will then take care of delivering it to the patient app. An example of recommendation JSON object is depicted in Figure 8.


```
{
   "alertType": "advice.connecare.irbll.AutomaticCustomRecommendations",
   "creationDate": "2018-10-08T15:48:28.953+02:00",
   "expireDate": "2018-10-09T15:48:28.953+02:00",
   "priorityLevel": 1,
   "recipient": "2c9380856392bd100163df4242f6010f",
   "target": "2c9380856392bd100163df4242f6010f",
   "status": "ACT",
   "extraParameters": {
      "Description": "Dear Gio, you did it with activity sedentary:
             38 minutes! I'm so proud :) :)",
      "Title": "New recommendation message!"
   },
   "comments": ""
}
```


Figure 8 Exemplary recommendation messages in JSON format.

With respect to point §6, it is worth mentioning here a mechanism put in place to accommodate testing and incremental release to production environment, as well as enable clinical partners to carefully check and assess the quality and adequacy of the textual messages sent by the RS to the real patients enrolled in CONNECARE. The RS features a **whitelisting mechanism** which allows fine-grained control over who gets the recommendation messages, and who does not. In particular, a configuration file enables to explicitly decide:

- Whether an entire site has to get recommendations, or not
- Which patients in a given site (tenant) should get recommendations, or which patients should NOT

This enables, for instance, to check how the RS behaves in production with a few whitelisted patients, then to later expand to all the available patients (without the need to list each of them individually) when the RS behaves as desired, and, if needed, to do so while excluding some specific patient (for instance because it explicitly doesn't want to get recommendation messages).

6 Evaluation

In this section we report on the evaluation performed to assess impact of the RS on adherence levels during time. First, we give context to the evaluation itself by overviewing the data upon which evaluation is based, then we focus on evolution over time of daily adherence levels, and of recommendation kinds, both globally and focusing on specific patients resembling particularly meaningful results.

6.1 OVERVIEW DATA

The RS system has been released in CONNECARE production environment at the end of April 2019, when it started delivering messages to a restricted group of patients selected for testing (thanks to the RS “whitelist” mechanism): 2 in Lleida, and 2 in Assuta. Release in Groningen has not received approval, as the ethical consequences brought along by the RS were deemed worth of further research, and the RS itself not ready for production. Then, after more than 3 full months of monitoring (the last days of April and May, June, July), the RS operations have been extended to a pool of **32 patients** in August 2019: 21 in Lleida and 11 in Assuta (**16 females**), 22 for Case Study 1 and 10 for Case Study 2, **age 75 ± 9.8**.

During the whole period when the RS run in CONNECARE, data gathered about daily adherence levels to prescriptions is highly sparse and irregular for a number of reasons: patients forgetting to synch data (despite reminders), temporary network problems, RS downtimes for testing adjustements, and similar. Hence, the analysis following has been concentrated in specific weeks of August where data were mostly available. The specific time frames considered in each analysis will be explicitly stated when due.

6.2 ADHERENCE

A natural metric to measure impact of RS on patients’ habits is daily adherence to prescription goals, and, in particular, how such adherence evolves during time when patients do receive recommendation messages: is it improving? Is it worsening? Is it unaffected at all by the nudges sent by the RS?

Figure 9 shows an overview of the data for the 32 patients receiving recommendations, focused on a two weeks time frame in August (surprisingly, an active period for the considered patients despite hot temperatures registered across sites) and on the four physical activities subject of prescriptions by clinical personnel (hence, of recommendations): light physical activity (top-left, in blue), moderate physical activity (top-right, in yellow), number of steps (bottom-left, in green), and vigorous activity (bottom-right, in red). As emphasized by the regression lines overlayed on the scatter plots (linear for steps, polynomial with order 3 for the other activities, confidence interval 90%), adherence levels to steps, as well as moderate and vigorous activities have an improving trend, whereas adherence to light activities is less

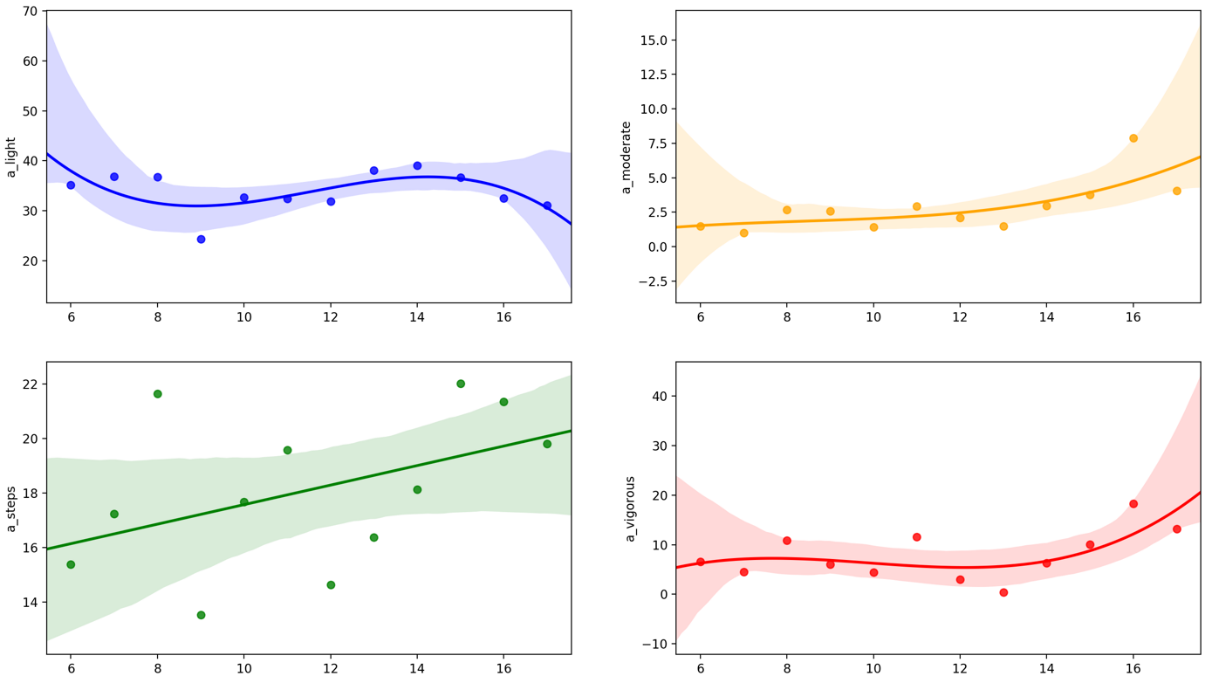

Figure 9 Average percentage adherence levels (y-axis), for the different monitored physical activities (light, moderate, vigorous, and number of steps), of 33 patients receiving recommendations, per day (x-axis, from 5 to 18 August, 2019).

stable and oscillates between improving and worsening adherence during the focused time window. Nevertheless, it is worth emphasizing here that once vigorous activity goal has been achieved, achieving moderate and light activity goals loses relevance, as they are in a sense implied by the vigorous one.

This is a first indication that recommendation messages may have a positive impact on patients' adherence to prescriptions, on average.

The modest size of the population of patients receiving recommendations (32) allows for a more specific analysis: in the following, we report similar plots but for specific patients, to emphasize the heterogeneity of cases and the different impact that the RS had on the patients.

For instance, patient 1 (unique anonymous ID displayed in picture) is an 88 years old female enrolled in Case Study 1 in Lleida. Her adherence levels trend for the two weeks are depicted in Figure 10: being enrolled in Case Study 1 in Lleida, the patient had only prescriptions for light activity (blue) and number of steps (green), and the impact of RS messages is difficult to assess, as steep improvements are followed by similar worsening.

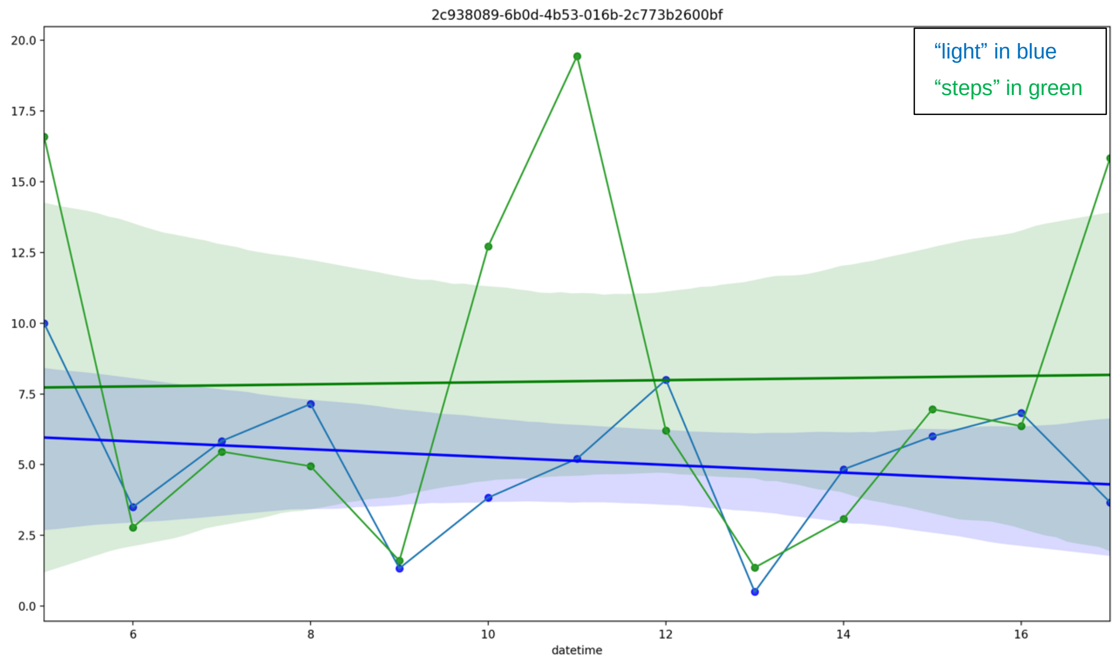

Figure 10 Difficult to assess impact of RS for this patient, as adherence levels are modest (0-19%) and highly irregular.

Patient 2 is an 84 years old female enrolled in same case study same site (Case Study 1, Lleida). Looking at her adherence levels over time highlights an improving trend for both prescription goals, which are also met in more than an occasion for light activity (adherence at or above 100%)---see Figure 11.

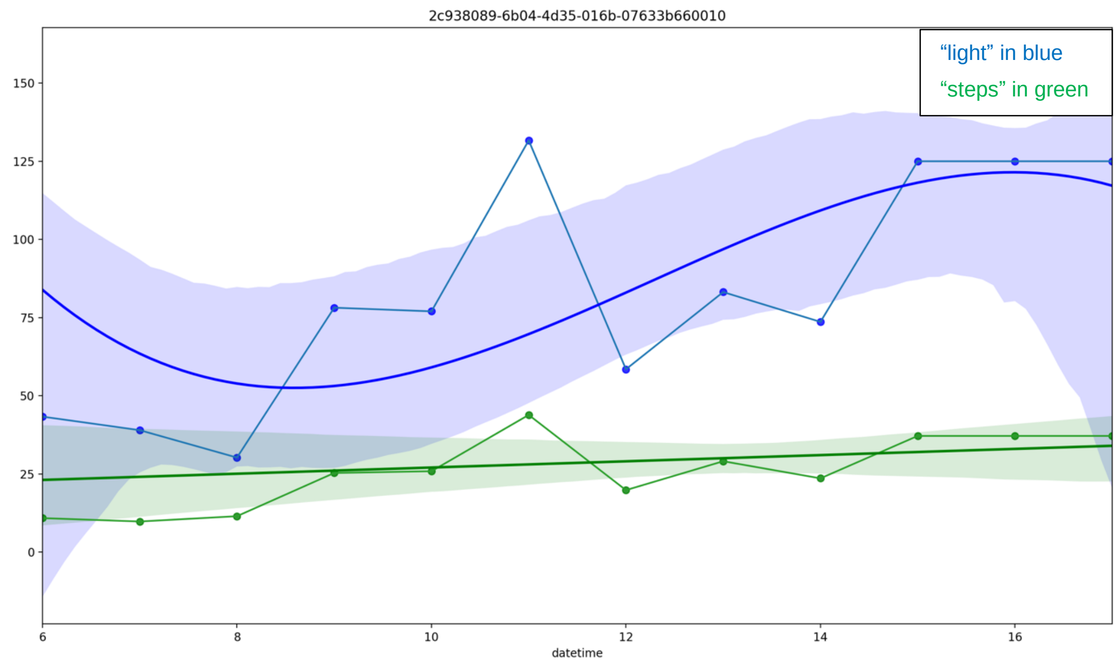

Figure 11 Positive impact of the RS, as improvements are steady.

Moving to Assuta site and Case Study 2, patient 3 is a 66 years old male whose adherence levels over time are highly irregular as well, as depicted in Figure 12. Steady improvement across prescription goals can be seen, especially in moderate and vigorous activities, where starting from 0 adherence peaks of ~60% for moderate and even goal achievement for vigorous are met.

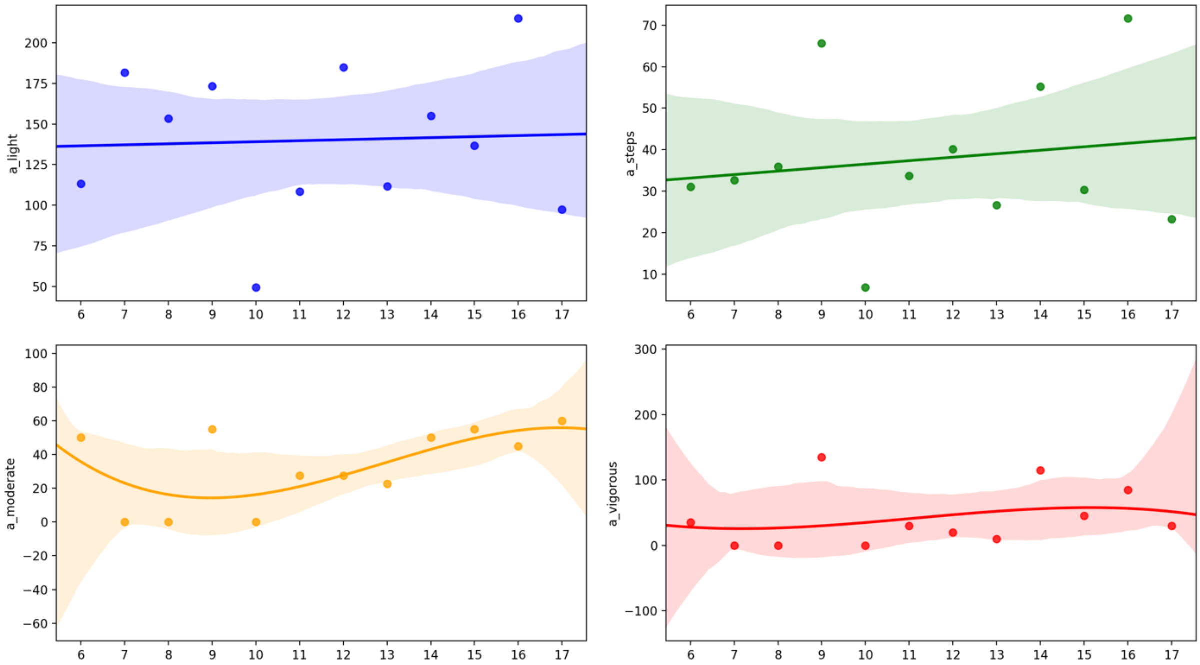

Figure 12 Despite irregularities, steady improvement with some notable peak can be easily detected for each physical activity prescription.

Finally, for the sake of transparency and completeness, Figure 13 shows the case of patient 4, a 67 years old male enrolled in Case Study 1 in Assuta, whose adherence is worsening in all physical activities except for moderate activity (orange line, top-left). Although it is difficult to detect the root cause of this results by merely looking at RS data, we must consider the possibility that receiving nudges and warning messages is not enough to push the patient towards healthier habits, and that possibly alerting the responsible professional may improve the situation.

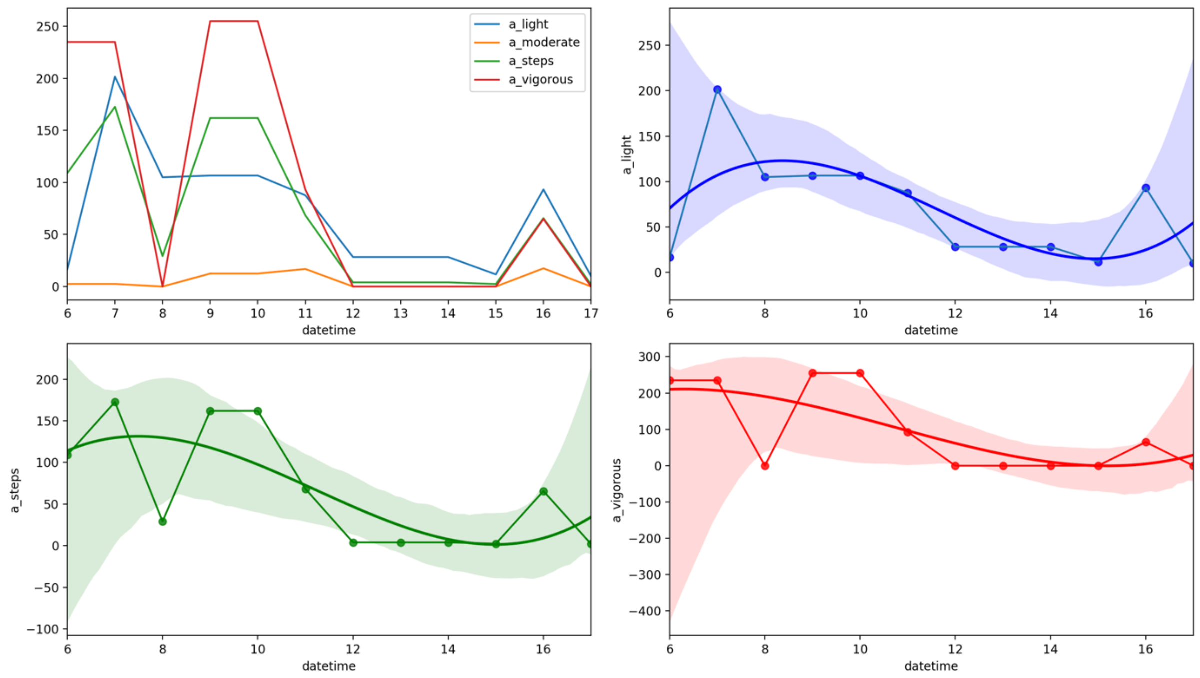

Figure 13 An example of worsening adherence despite, or more alarmingly due to, recommendation messages.

6.3 RECOMMENDATIONS

Another natural metric to analyze with the goal of assessing impact of RS on patients' habits with respect to prescriptions is to look at the kind of recommendation messages they receive: as awards indicate goal achievement and alerts a missed prescription, for instance, the evolution in time of the number of recommendations of these two kinds can give clues about RS impact. Namely, if awards increase over time while alerts decrease, it can be claimed that the impact of the RS is positive.

Figure 14 depicts the number of messages received by the pool of 32 patients in the same two weeks time window (from 5 to 18 August, 2019) considered in previous section: ALERT recommendations in blue, AWARD in orange, MOTIVATIONAL in green, and WARNING in red. The overall trend of each recommendation type is increasing except for WARNING messages which seem to have reached a sort of plateau thus started decreasing. Differently from the average adherence metric used in previous section, looking at the overall trend does not give clear indications about whether the RS is having positive, negative, or no impact on patients: both awards and alerts exhibit an increasing trend, thus is the situation improving or worsening?

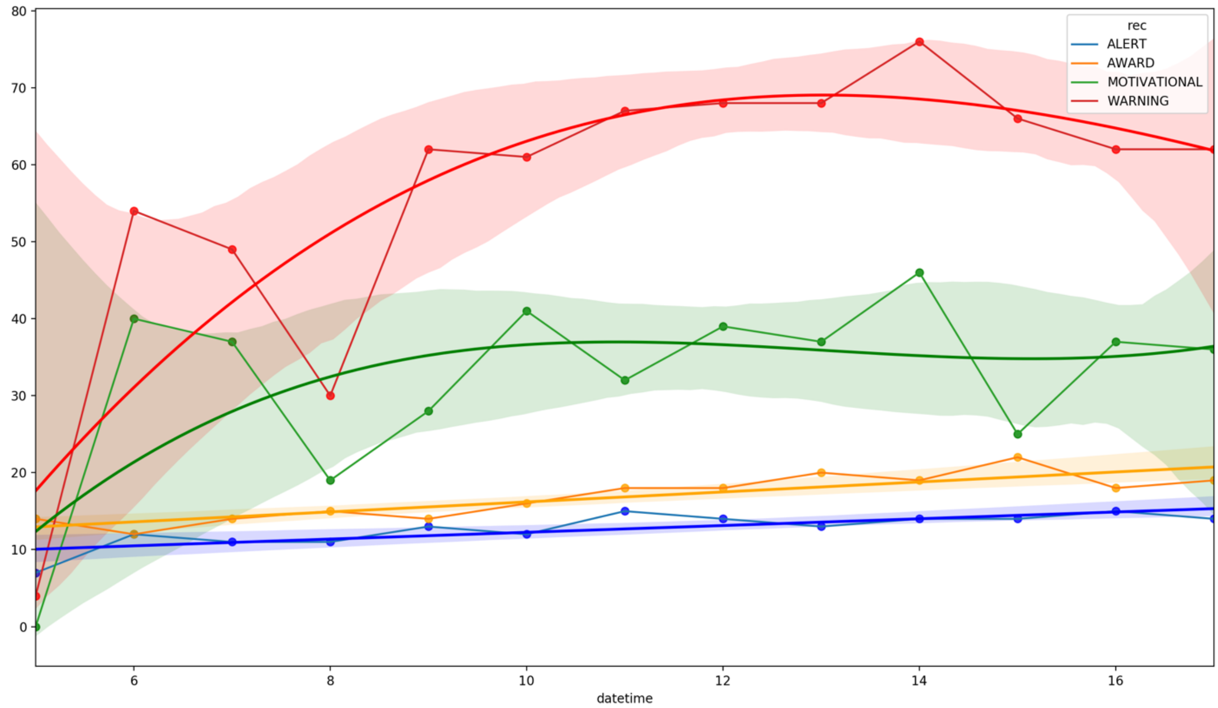

Figure 14 Number of recommendations (y-axis) received by patients, per kind (see Section 3.3), per day (x-axis).

A more clear answer to the question above is given by Figure 15.

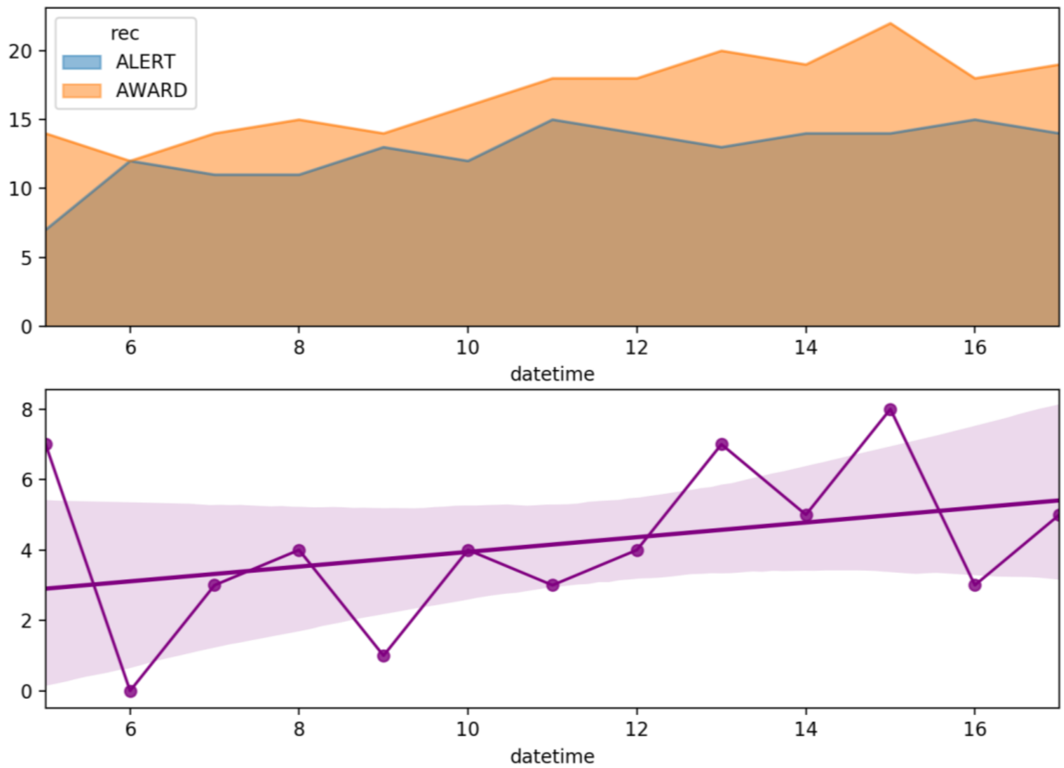

Figure 15 Awards and alerts in time (top, not stacked), and their difference (bottom).

Both charts zoom on awards and alerts as presented in Figure 14 with the goal of emphasising the difference between the number of awards received and the number of alerts, which is a direct measure of the rate of goal achievement as regards physical activity prescriptions: in fact, AWARD messages are delivered whenever a patient achieve the prescription goal, whereas ALERT recommendations signal the opposite situation (goal has been not achieved). In the top plot the difference is the orange area in between awards and alerts, whereas in bottom plot it is the purple line connecting the scatter dots, which has been decorated with linear regression to better highlight the increasing trend. Therefore, since such a difference increases over time the RS can be said to have a positive impact on the rate of goal achievement, hence adherence of patients to prescriptions improves.

As done in the previous section, it is possible to focus on specific patients thanks to the small population size (32 patients), to highlight peculiar situations and the different impact that different kinds of recommendation messages may have. In fact, up to now we mostly analysed awards and alerts, but it is also interesting to study how motivational and warning messages influence patients' behaviour, in particular as the former convey a more positive, encouraging message pushing patients towards goal achievement, whereas the latter are more alarming and warn the patient about potential non-compliance to prescriptions.

For instance, patient 5 is a 71 years old female enrolled in Lleida for Case Study 2.

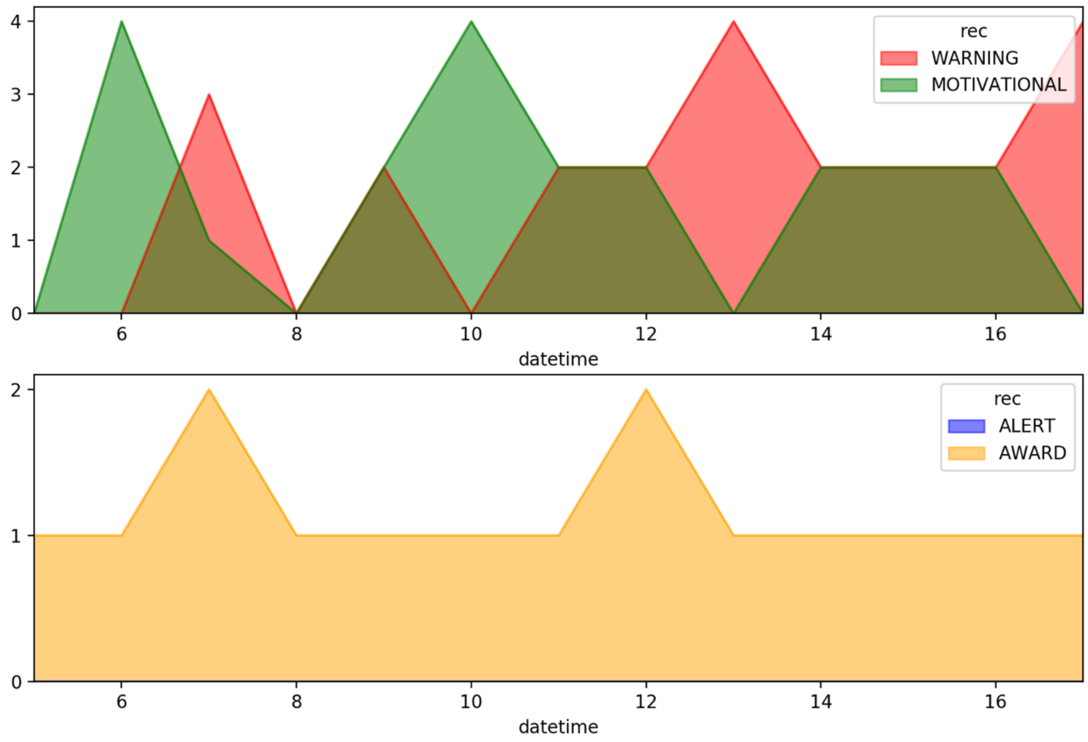

Figure 16 Patient whose awards (bottom) likely follow motivational messages (top, green) rather than warning (top, red).

The recommendation messages received by her are depicted in Figure 16: at the top, motivational messages and warnings, at the bottom awards and alerts (no alert received). By looking at both area charts together it is apparent how the best achievements (the double award earned on day 7 and on day 12) follow a spike in motivational messages. This may indicate that the patient is more sensible to positive encouragement messages rather than alarming warnings (that still apparently play some role).

Patient 6 is an 85 years old male patient enrolled in Case Study 1 in Lleida whose recommendations data shows a similar behaviour, as depicted in Figure 17: at the very beginning of the two weeks time window the patient is getting alerts (at the end of the day) for missing prescription goals, and warning messages (during the day, see Section 4) accordingly. Such warnings seem to have the intended effect as the patient starts achieving prescription goals consistently (also in more than one activity, as in day 15).

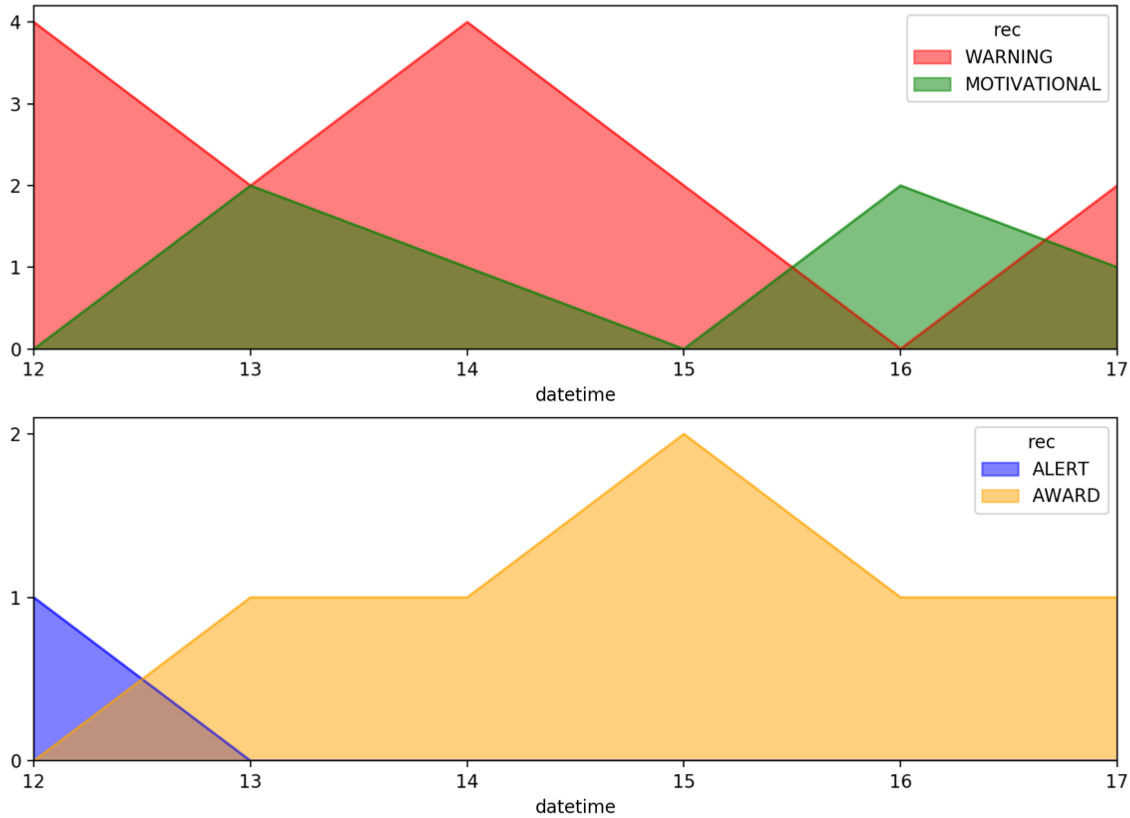

Figure 17 Another patient for which warning recommendations seem particularly effective.

A different case is that of patient 7, a 67 years old female enrolled in Case Study 1 in Assuta, for which warning recommendations are ineffective (but consider that in August in Assuta is very hot, as already said) as shown in Figure 18.

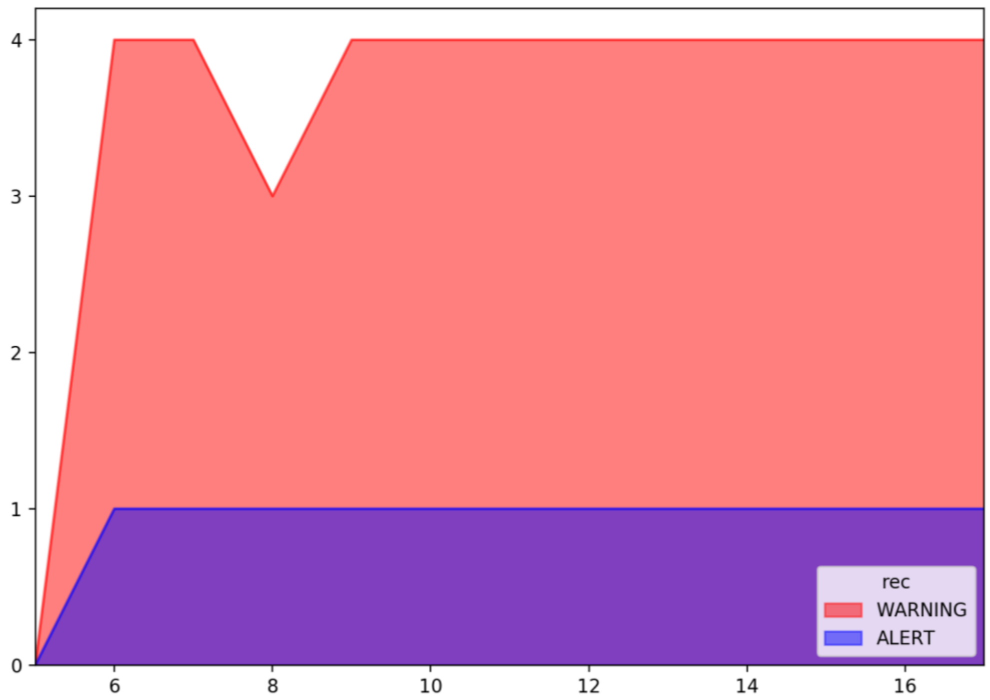

Figure 18 Totally ineffective warning recommendations.

The situation of patient 7 emphasises a limitation of the RS as currently deployed: since generation of recommendations of a given kind is based on adherence, low adherence always leads to warning messages, despite their ineffectiveness. A way out of this “dead-end” would be to have the RS change strategy automatically when a message is recognised as ineffective (in this case, to start sending motivational messages instead). This is quite difficult to obtain as implies some form of online data analysis, but could be subject of future research.

Finally, the case of patient 8, a 62 years old male from Assuta enrolled in Case Study 2 reported in Figure 19, shows a nice combination of motivational and warning messages to help the patient increase its adherence to prescription goals.

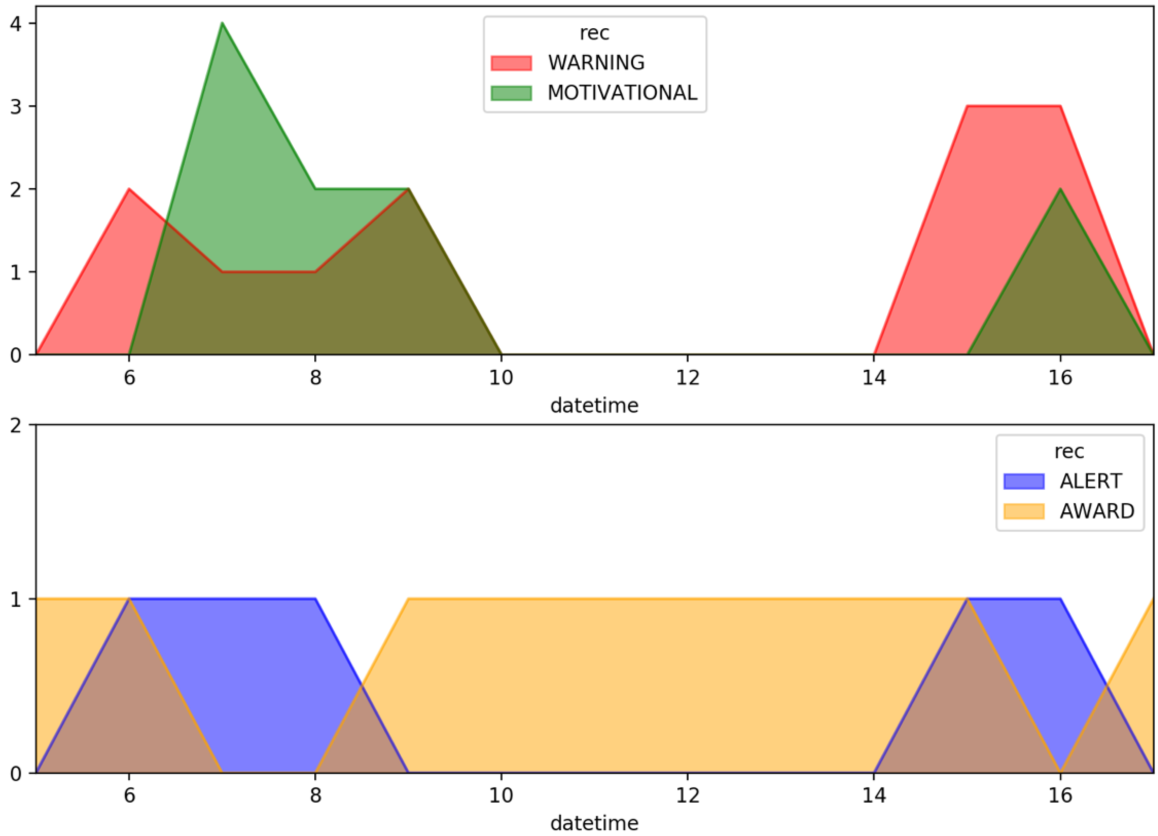

Figure 19 A case in which motivational and warning messages combined help the patient achieving prescription goals.

7 Opportunities for future development & exploitation

The RS software has been designed and developed with **flexibility** and **interoperability** in mind, so as to promote as best as possible future exploitation, extensions, and transferability across domains. Such a flexibility articulates along two axis: *run-time configuration* and *design-time extension*.

The former is mostly enabled by the *strategy* and *policy* concepts leveraged by the RS, which allow to easily customise timing of messages, adherence thresholds for recommendation types, and extend the pool of sentence templates and token available. Also the whitelisting / blacklisting methods allows to easily expand the list of patients receiving (or not) recommendations. Further translation languages can also be added without the need of stopping the systems.

As far as design-time extension is concerned, the notions of *prescription*, *fulfilment*, *adherence* and adherence *profile*, have been designed to readily encompass a slew of different scenarios: for instance, prescriptions can be configured with custom deadlines, as even if currently the RS in use in CONNECARE uses daily goals, nothing prevents to set a weekly goal to be monitored along a whole week. In such a case, fulfilments are accumulated day after day and according to the same "ideal patient" criteria recommendation messages can be sent day after day until deadline expires or goal is achieved. Also, currently the subject of recommendations are physical activities, such as walking for a certain amount of steps or doing light, moderate, vigorous activities, but this is yet another concept modelled in the RS implementation with generality in mind: the concept of *metric* (as something which can be measured). By including new metrics in the RS source code (e.g. sleep) along with their strategy to compute adherence, new recommendations can be generated for such new metrics. Along this line, an extension which has been already subject of some experiments, although still as a prototype hence not ready to be tested with CONNECARE patients, is the inclusion in the RS of recommendations based on the specific questionnaires prescribed by professionals to patients in each site. There, the percentage of completed questionnaires, the pace at which patients respond, and even some of the replies are used to craft another kind of personalised message, with the twofold goal of improving the frequency of replies, and the questionnaire outcomes.

As regards *integration* with different systems the RS exploits standard service-oriented technologies: being implemented as a RESTful web service exploiting HTTP and JSON, it is virtually interoperable with any other service regardless of the programming language and executing platform adopted. For instance, integration with another back-end service (e.g. a new service replacing the CONNECARE SMS) or data visualisation through a web frontend (e.g. the SACM or another we-based portal) can be easily achieved with minimal effort, if desired.

8 Conclusion

The Recommender System has proven to be a valuable service for patient engagement and empowerment, capable of increasing adherence of patients to prescription goals while also promoting healthy habits regarding physical activities.

Tests performed on real patients enrolled in CONNECARE clinical studies and thoroughly discussed in Section 6 confirmed two crucial and complementary things:

- The RS has the potential of **positively impact** on the daily habits of recipients of personalized messages, there including improving adherence to clinicians' prescriptions
- The RS has shown **no negative impact** on adherence levels of patients, even when the number of messages sent per patient was relatively high (3~4 per day)

The former result confirms that recommendation messages, or more in general nudges, delivered to patients with the goal of (i) raising awareness of their conditions and (ii) encouraging healthy habits and motivating achievement of goals are an effective means to increase adherence to prescriptions. The latter result reassures about the risk of counter-effects such as bothering patients due too many messages sent. It is worth emphasizing that, especially the latter result, these considerations are extremely sensitive to the human factor, that is the person to whom messages are directed, and that careful fine-tuning of timing and frequency aspects should be done whenever applying this sort of system to other domains or intended audience.

9 Bibliography

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10 List of Figures