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CONTENTS

Spatio-temporal Analysis of Air Quality Index and Risk Simulator for Health Infrastructure Planning During COVID-19 Pandemic

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***Abstract*—The COVID-19 pandemic has thrown light on the need to prioritize and improve the existing health systems globally. Especially in South Asia, the pandemic has left a long-term scar on the economy and people's lives. It has burdened the cities to improve their overall health and medical infrastructure facilities. Though several makeshift solutions developed in due time provided intermediate relief to the cities, a long-term solution to make the city self-sufficient in terms of resources, especially in situations like the pandemic becomes necessary. Thus, a collaborative approach to bring about an overall change in the existing health system is required. In this work, we provide an in-depth Spatio-temporal analysis of the air quality in an Indian smart city - Pune and propose a simulator tool that assists authorities in making informed decisions on adding medical infrastructure facilities. This simulator tool takes in static demographical inputs, user inputs related to the city infrastructure, and forecasted dynamic inputs like critical zones or hotspots along with the overall air quality levels to predict the risk scores of wards. This numerical predicted score is an indicator of the ward level risk. Concerned authorities can use this tool to foresee the ward conditions and understand the impact of the risk score in a ward with incremental variations in the ward facilities during the pandemic. Further, the Spatio-temporal analysis of the Air Quality Index (AQI) shows how certain strategies and guidelines imposed during the pandemic can help bring in significant improvement in the environmental health condition of the city. It provides a detailed summary of the variation in the air quality index and pollutant concentrations in Pune from March 2020 to July 2021. Overall, this work provides a retrospective view on the impact of demographic, medical infrastructure, and environmental parameters on the ward condition and how improvement in these parameters can help cities ameliorate the existing health system in challenging times like the pandemic.**

Keywords*—*COVID-19; air quality index; risk score.

I. Introduction

The research presented in this paper is an extension of our previous work [1]. Coronavirus disease (COVID-19) is an infectious disease caused by the SARS-CoV-2 virus. It eventually started spreading across the globe and soon became a matter of international concern. The World Health Organization (WHO) declared this disease a pandemic in March 2020. Since then, it has caused more than 526 million cases across the globe claiming millions of lives [2].

Like several other countries around the world, India also faced challenges related to the economy, infrastructure, medical facilities, human resources, and environment due to the pandemic. The second wave of COVID-19 in India has had severe consequences in the terms of escalating positive cases, shortage of medical infrastructure facilities reduced medical supplies for treatments, and increased death rates, particularly in the younger population [3]. Scientists and researchers across the globe have been trying to identify the causes for the same. However, the reason for this is still not apparent and is beyond current scientific explanations. Purva et al. [3] believe that India's poor air quality index could be a potential factor as to why the spread of the infection has been severe across the country. Given that 9 of the 15 most polluted cities globally are in India, it could be postulated that the ability of the Indian population to fight against COVID-19 is impaired because people's lungs are severely affected by air pollution. Further, a study by Comunian et al. [4] suggest that an increase in fine particulate matter $PM_{2.5}$ is associated with an increased risk of COVID-19 infection. The atmospheric particulate matter could create a suitable environment for transporting the virus to greater distances. This could induce inflammation in lung cells and exposure to the particulate matter could further increase the susceptibility and severity of the COVID-19 patient symptoms.

In our previous work [1], we studied the effects of COVID-19, particularly in the smart city of Pune, a western Indian state of Maharashtra, and devised a scoring mechanism to dynamically predict the risk levels and the environmental health in the city. This work is an extension of the same. In this paper, we further do an in-depth analysis of the air quality conditions in Pune city during the period of the COVID-19 pandemic and implement a simulator that helps authorities foresee the reduction of risk scores in the city with the addition of medical infrastructure facilities during the pandemic. The timeline of the COVID-19 wave in India during our study can be broadly divided into three phases: Phase 1

(March 2020 to Oct 2020), Maintenance Phase (November 2020 to February 2021), and Phase 2 (March 2021 to June 2021). In our paper, we select the following months in each of the three phases for detailed analysis. Phase 1 (March, April, May 2020), Maintenance Phase (January, February, March 2021), and Phase 2 (May, June, July 2021). According to reports [5], during the second wave, Maharashtra was India's worst-affected state, just as it was in the first wave of COVID-19. A total of 35 percent of cases were reported in the first wave, while 6 percent of cases were registered during the Maintenance Phase. The second wave reported 59 percent cases in Pune. Pune being a smart city has taken several initiatives to fight against this pandemic. Right from setting up a command-and-control center for the supervision and community surveillance of containment zones, tracking the number of positive patients, and planning health care resources, Pune smart city team has been actively providing support for the COVID-19 management. However, due to the unprecedented nature and non-anticipated spread of the virus, the 2nd phase of the pandemic had a devastating effect on the city. In this work, we analyze the ward level risk scores with changes in the ward medical and infrastructure facilities and propose tools, and suggestions to help reduce the risk levels in such situations. The contributions of this work are as follows:

- **Spatio-temporal analysis of Air Quality Index (AQI) during the pandemic**: Descriptive statistics are used to assess the Spatio-temporal variations of various environmental attributes including AQI, sound (dB), ozone (ppb), NO_2 (ppb), SO_2 (ppb) and particulate matter $PM_{2.5}$ (µg/m^3) during the 3 phases of the COVID-19 pandemic. Spatial analysis is used to study the variations in attributes across the wards. While temporal analysis is used to study the variations in attributes of the ward over time. Quantification of the pollutant levels across the study period is provided to understand how the lockdown impacted the AQI levels in the city. Suggestive measures to control the degradation of ward environmental health are provided.
- **A simulator tool to analyze the reduction in the ward level COVID-19 risk score with incremental change in the ward medical and infrastructure facilities**: As introduced in our previous work [1], we had developed an aggregated data-rich model that predicts the ward level risk scores. This numerical score was indicative of the overall risk associated with the ward in terms of its medical infrastructural health, demographics, and environmental health. Based on the risk scores, the wards were categorized into risk zones - Severe (100-80), High (80-60), Moderate (60-40), Low (40-20), and Very Low (20-0). The higher the risk value, the greater the COVID-19 risk. In this work, we provide an extension to this model to help simulate and analyze the reduction in the ward level COVID-19 risk score with incremental change in the ward medical and infrastructure facilities. The inputs to the tool include static inputs like the ward demographics (ward population, literate population, children under the age of 6, number of houses in the ward, family size, and working population), dynamic inputs like the number of hotspots, health score of wards along with user inputs like additional hospitals and beds to be added. The dynamic inputs are forecasted based on previous data while the user inputs are directly fed to the model. Training data is prepared to reflect the ward attributes and is used to train the model. Based on the user inputs, required features are forecasted and then fed to the model to get the corresponding risk scores. This simulator tool provides detailed information on the impact of critical attributes including medical infrastructure facilities (hospitals, beds in hospitals), ward demographics (population statistics), and ward environmental health (AQI, population, and tree count) on the ward risk levels. With the help of this tool, concerned authorities can foresee the risk scores for various wards in Pune Municipal Corporation (PMC)-Pune, categorize the wards into risk zones based on the risk scores, and try to understand the impact of incremental improvement in the ward medical infrastructure facilities on the ward risk via simulation.

Overall, the work in this paper provides granular ward level AQI statistics and localized information dynamically considering the change in the attributes. The simulator tool provides adequate information to concerned authorities to plan and further improve the infrastructure and medical facilities in the ward. The simulation helps them understand how improving the ward facilities will impact the risk score and in turn their categorization to risk zone.

The remaining part of the paper is organized as follows. Section II describes the overall methodology, and Section III provides technical information about the data sources, data analysis, and modeling with suitable graphs and plots. Section IV presents the discussion of the results while Section V describes the conclusion of our approach.

II. Methodology

This section provides details on the study area and briefly explains the contributions of this research.

A. Study Area

Pune is the seventh most populous city in India and the second-largest city in the state of Maharashtra, with an estimated population of 7.4 million as of 2020 [6]. Pune is also the 101st largest city in the world by population. It is also one of the fastest-growing cities in the Asia-Pacific region. The Mercer 2019 Quality of Living rankings evaluated local living conditions in more than 440 cities around the world where Pune ranked at 143 [7]. PMC is the civic body that governs the inner limits of Pune spread over an area of 331.26 sq. km. Based on the 2011 census, the data from 144 wards of the PMC region is considered in this study [8]. The government of India has started the National Smart Cities Mission program to develop smart cities across the country. The Union Ministry of Urban Development in India is responsible for implementing this mission in collaboration with the state governments of the respective cities. Projects were launched in 20 cities selected in the first batch of the mission through a city challenge competition. Pune was one among them that was shortlisted by the Minister of Urban Development.

B. COVID-19 Phase-wise AQI Analysis in Pune

Air Quality data [9] of Pune city is collected, pre-processed, and analyzed over the study period, Phase 1 (March 2020 to May 2020), Maintenance Phase (January 2021 to March 2021), and Phase 2 (May to July 2021). Ward-wise variations across months and days are studied in detail. We summarize our findings phase-wise and interpret the reasons for the variations in the parameter. This sub-section provides an overview of how the overall AQI has varied in Pune as a result of various precautionary measures that were taken during the study period.

C. Simulator tool to analyze the reduction in the ward level COVID-19 risk score with incremental change in the ward medical and infrastructure facilities.

This tool helps users analyze the variations in the risk score of the ward that is calculated based on essential parameters like the ward demographics, environmental health as well as the current medical and infrastructure facilities. The simulator tool is built on top of the Gradient Tree Boosting-based risk prediction model proposed in our previous work [1]. Based on the current risk score of the ward, users can vary the input features and understand their impact on the risk scores. Improvement in the ward medical facilities will reduce the risk level in the ward and its impact can be easily understood with this simulator. This makes it easier to help city authorities plan and improve the ward medical facilities in challenging times like the pandemic. Appropriate user interface screens are implemented to access the features of this simulator tool.

III. Implemention and Results

This section provides details on the data sources involved, analysis, and data modeling along with the results and supported user screens.

A. COVID-19 Phase-wise AQI Analysis in Pune

1) Data Sources: Air Quality data [9]: The Pune Urban Data Exchange (PUDX) platform provides data related to the air quality sensors installed in several parts of Pune city. 50+ sensors installed across the city actively measure the concentrations of pollutants. The sensors provide AQI readings every 15 minutes. A pipeline is created, and a job is scheduled to collect this data regularly. The collected sensor data is then mapped to the appropriate wards.

2) Data Analysis: Spatio-temporal analysis of AQI in PMC-Pune: AQI for the wards in Pune across a period of months is studied in detail. We studied the AQI over the study period, Phase 1 (March 2020 to May 2020), Maintenance Phase (January 2021 to March 2021), and Phase 2 (May to July 2021). According to the study [10], Pune had been ranked 299th on the air pollution index across the globe, 8th in the state, and 74th across the country. However, in 2020, during Phase 1, we saw a significant decrease in the AQI levels across wards in PMC-Pune, especially during April. The average AQI levels saw a decrease of 36% from March to May. This reduction can be majorly attributed to the restriction in activities that were imposed with a nationwide lockdown persisting across these months. Figure 1 shows the average AQI levels in PMC-Pune during this phase. We also studied the variations of AQI at individual ward levels both month-wise and day-wise. Table I below shows the month-wise AQI values in 10 wards during Phase 1 and variation in the AQI between May-20 and March-20.

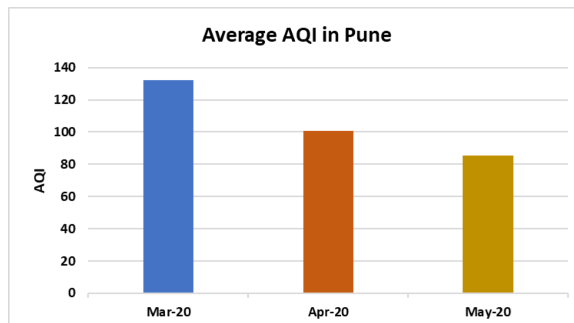

Figure 1. Average AQI in PMC Pune during Phase 1

TABLE I
Ward-wise variation in AQI during Phase 1

Ward	Mar-20	Apr-20	May-20	Variation(%)
AundhGaon	107.74	111.62	119.79	11
Baner-Balewadi	49.38	33.23	30.94	-37
Hadapsar	195.61	141.25	149.66	-23
Lohagaon	87.03	55.63	13.04	-85
Parvati Darshan	138.01	104.89	94.47	-32
PhuleNagar	156.04	90.73	96.99	-38
S.G.Rugnalaya	77.43	65.32	28.49	-63
S.Mahavidhyalaya	65.15	53.25	55.08	-15
Ved Bhavan	117.54	64.75	42.84	-64
Wadiya College	124.94	98.58	100.26	-20

The negative variation indicates improvement in the AQI level while a positive variation shows how it has degraded over time. Most of the wards showed improvements in their air quality index. Some wards showed as little as 2% improvement in their AQI levels while a few others showed 100% improvement. It can be noticed that the AQI levels were relatively lower in April-2020 when strict lockdown rules were imposed across the city. However, by the end of May, the unlock phases had begun. Increased activity during this period in some wards might have led to positive variation being seen in their

AQI levels. This significant decrease in various attributes can be contributed to the suspension of activities and restrictions imposed on citizens during the lockdown. Residential areas like Lohagaon, Kothrud, Baner-Balewadi, and many others as shown in Table I showed a significant reduction in attributes like AQI, sound, and pollutant concentrations with the imposition of lockdown. Figure 2 shows variations in Sound, NO_2, SO_2, $PM_{2.5}$ and Ozone levels during this phase across Pune. Month-wise and day-wise AQI variations of the ward, Baner-Balewadi during Phase 1 are shown in Figure 3.

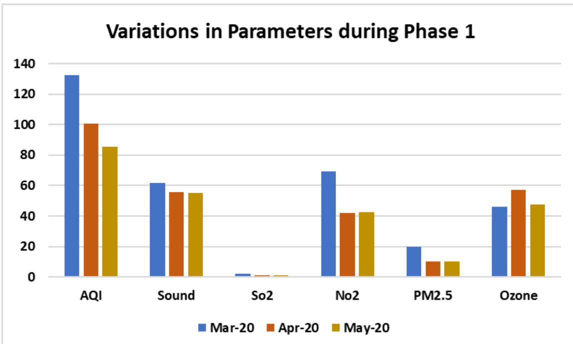

Figure 2. AQI Parameter variation during Phase 1

Overall, during Phase 1 PMC-Pune had

- 36.0% decrease in AQI level
- 11.0% decrease in Sound level
- 58.0% decrease in SO_2 level
- 39.0% decrease in NO_2 level
- 48.0% decrease in $PM_{2.5}$ level
- 2.0% increase in Ozone level

With the lifting of restrictions, activities across the country slowly began to resume after the first wave of COVID-19. During the Maintenance Phase from November 2020 to January 2020, there were a relatively lesser number of cases seen across the country. By the end of February, the cases saw a surge in number, and people started cautiously following the COVID-19 protocols. Overall, during this phase, the AQI levels decrease by 16% as shown in Figure 4. Figure 5 shows the variation in other AQI parameters.

This decrease in AQI levels was also reflected in some wards during this period. However, the effect of the relaxation of COVID-19 rules and protocols was seen in contributing to increasing the AQI levels in a few more. Table II shows the ward-wise variations across months in this period. Month-wise and day-wise AQI variations of the ward, Baner-Balewadi during the Maintenance Phase are shown in Figure 6.

Overall, during the Maintenance Phase, PMC-Pune had

- 17.0% decrease in AQI level
- 1.0% increase in Sound level
- 36.0% decrease in SO_2 level
- 20.0% decrease in NO_2 level
- 29.0% decrease in $PM_{2.5}$ level
- 114.0% increase in Ozone level

TABLE II
WARD-WISE VARIATION IN AQI DURING MAINTENANCE PHASE

Ward	Jan-21	Feb-21	Mar-21	Variation(%)
AundhGaon	93.89	88.69	81.92	-13
Baner-Balewadi	57.43	56.52	50.24	-13
Hadapsar	103.11	84.73	116.86	13
Lohagaon	98.38	84.55	83.55	-15
Parvati Darshan	139.55	101.83	104.97	-25
PhuleNagar	226.34	155.44	104.02	-54
S.G.Rugnalaya	101.33	104.06	103.85	2
S.Mahavidhyalaya	108.69	119.04	135.93	25
Ved Bhavan	79.56	68.19	62.57	-21
Wadiya College	161.18	101.89	114.05	-29

According to a study, [11] a high NO_x level reacts with Ozone and mops it up. The Ozone that escapes to cleaner areas has no NO_x to further cannibalize it and as a result, Ozone concentration builds up in these areas. This explains the increase in concentrations of Ozone in the atmosphere during this phase.

According to the report, [6], nearly 59% of the cases in Pune were reported during Phase 2. It was noticed that the numbers were increasing rapidly. With changing symptoms unlike those seen in Phase1, people in the age group of 20 to 45 years were mainly affected during this phase. They showed symptoms like low-grade fever and severe breathlessness. During this phase, Maharashtra was one of India's worst-affected states in the country. The Chief Minister of Maharashtra then announced a lockdown starting from the second week of April that lasted till May. We analyzed the AQI levels during this phase as shown in Figure 9 and other parameters as shown in Figure 8.

A few wards saw drastic changes in the AQI levels during this phase. Table III shows the ward-wise variations across months in this period. Month-wise and day-wise AQI variations of the ward, Baner-Balewadi during Phase 2 are shown in Figure 9. Overall, during phase 2, PMC-Pune had

- 6.0% decrease in AQI level
- 1.0% increase in the Sound level
- 21.0% increase in SO_2 level
- 9.0% decrease in NO_2 level
- 21.0% increase in $PM_{2.5}$ level
- 30.0% decrease in Ozone level

Though levels of AQI, Ozone, and NO_2 decreased during this period, there was a significant increase in the SO_2 level. With the increase in COVID-19 cases, cities began manufacturing essential medical aids including the PPE kits in large quantities demanding higher energy consumption and in turn leading to higher emissions of SO_2 from the power plants. This may have led to increased SO_2 levels in the city.

Utilizing a mix of epidemiological data, satellite data, and other monitoring information from around the world, Pozzer et al. [12] estimated that on average, 15% of worldwide deaths from COVID-19 may be linked to chronic exposure to air pollution. They also found out that an increase in exposure to hazardous air pollutants is associated with a 9% increase

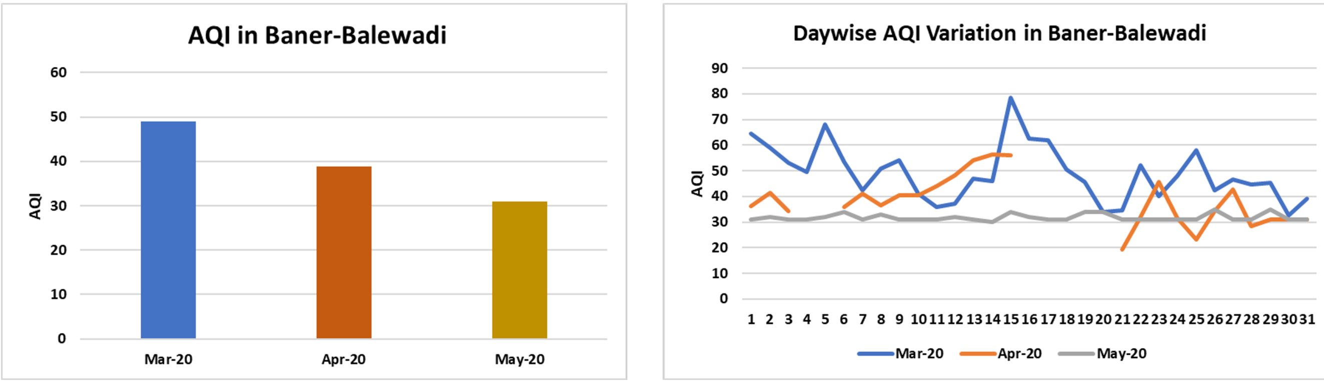

Figure 3. AQI variations in Baner-Balewadi during Phase 1

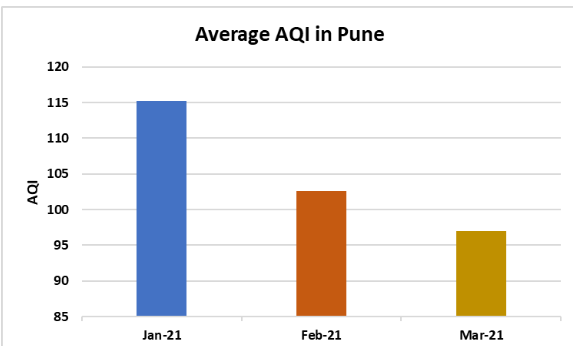

Figure 4. Average AQI in PMC Pune during Maintenance Phase

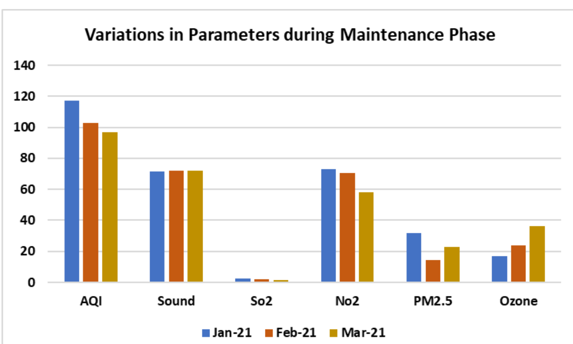

Figure 5. AQI Parameter variation during the Maintenance Phase

TABLE III
WARD-WISE VARIATION IN AQI DURING PHASE 2

Ward	May-21	Jun-21	Jul-21	Variation(%)
AundhGaon	74.75	74.91	73.22	-2
Baner-Balewadi	22.87	39.82	36.57	60
Lohagaon	59.89	56.18	67.29	12
Hadapsar	56.52	53.05	67.81	20
Parvati Darshan	65.31	59.34	64.37	-1
PhuleNagar	73.29	64.31	58.39	-20
S.G.Rugnalaya	91.34	61.79	59.83	-34
S.Mahavidhyalaya	81.30	85.30	73.97	-9
Ved Bhavan	65.31	74.32	70.42	8
Wadiya College	69.75	65.04	62.96	-34

TABLE IV
AQI, COVID-19 CASES AND FATALITY RATE

	AQI	COVID-19 cases (%)	Fatality(%)
Phase 1	102.14	35	52
Maintenance Phase	104.98	6	8
Phase 2	70.68	59	40

in death among patients with COVID-19. With this as the reference, we summarized the AQI levels along with the total COVID-19 cases reported (in %) and the fatality rate against the reported cases in Pune in Table IV.

During the Maintenance Phase, there was an increase in the average AQI level and the fatalities that occurred in the reported cases. It may be ascertained that higher concentrations of air pollutants in certain wards may have caused increased respiratory stress, thereby increasing vulnerability to severe illness during Phase 2 of COVID-19. As reported by another study by Wu et al. [13], just a small increase (1 microgram per cubic meter) in long-term average exposure to fine particle pollution is associated with an 11% increase in the COVID-19 death rate for that country. We summarized the average variations of pollutant concentrations in Pune across the study period in Table V. Most of the parameters saw an increase in their concentration levels during the Maintenance phase or the relaxation phase. This increase in levels may have contributed to the surge in cases during Phase 2. Figure 11 shows the variations of pollutants across the study period. From this, we can essentially conclude that the higher the air pollution index and the pollutant concentrations, the more it correlated to poor health outcomes due to COVID-19 in Pune. Figure 10 shows various diseases attributed by air pollution in India in 2019 [14]. It can thus be inferred that with certain restrictions and measures, the concentration of pollutants can be significantly reduced in the city. This will not only help in improving the overall air quality but will also help prevent premature deaths, morbidity issues, and several other serious respiratory diseases in people. It will largely contribute to preventing the aggravation of respiratory stress, especially during challenging

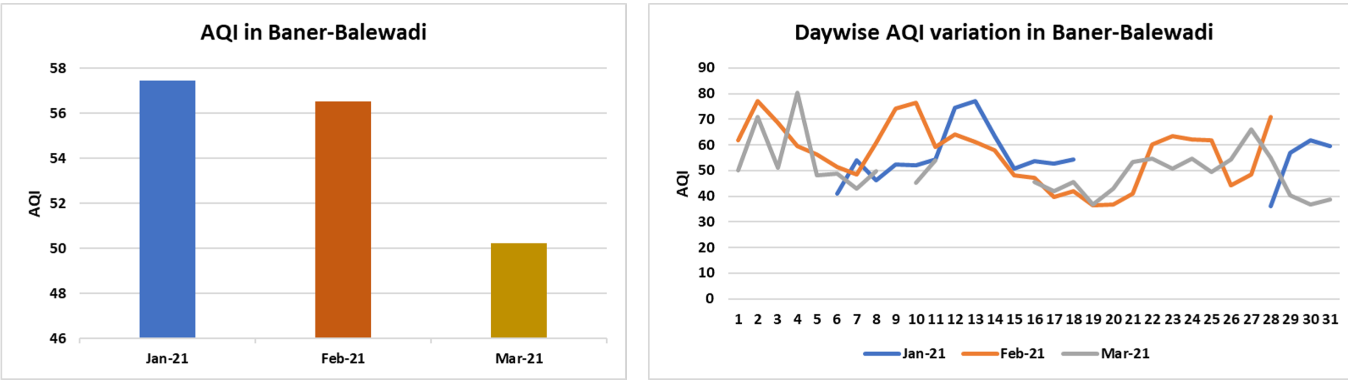

Figure 6. AQI variations in Baner-Balewadi during the Maintenance Phase

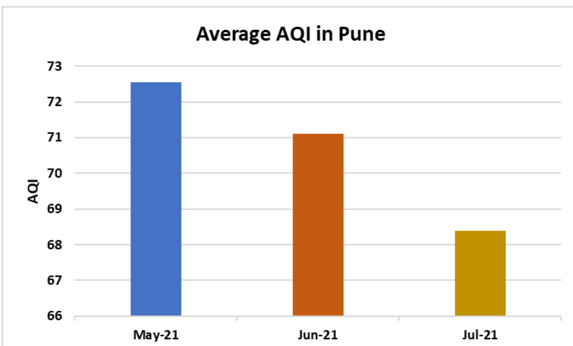

Figure 7. Average AQI in PMC Pune during Phase 2

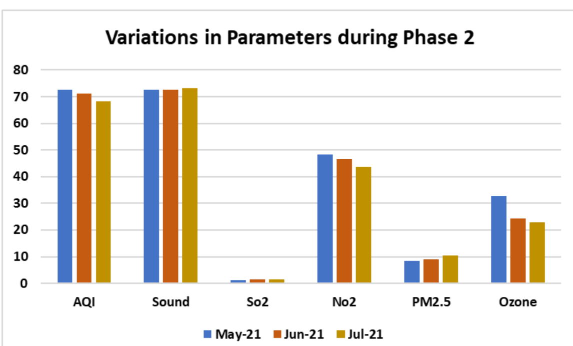

Figure 8. AQI Parameter variation during Phase 2

times like the pandemic.

B. Simulator tool to analyze the reduction in the ward level COVID-19 risk score with incremental change in the ward medical and infrastructure facilities.

This tool helps users analyze the variations in the risk score of the ward that is calculated based on essential parameters like the ward demographics, environmental health as well as the current medical and infrastructure facilities. As described in our previous work [1], we had developed a comprehensive risk scoring model that considered thirteen features as described in Table VI to model the risk level of the ward.

The data collected for these features was used to train and test the model. Several machine learning-based prediction algorithms like Linear Regressor, Random Forest, K-Nearest Neighbor, and Gradient Tree Boosting were used to predict the risk scores based on the thirteen input features selected. The predicted risk score values and their variations for the wards across days were studied in detail. The average prediction error rate of models using various machine learning algorithms was compared and the Gradient Tree Boosting algorithm was selected to predict the ward level risk scores. The work in this paper provides an extension to this model. Based on the current risk score of the ward, users can vary the input features like the number of beds(x) and hospitals(y) and understand their impact on the risk scores. Improvement in the ward medical facilities will reduce the risk level in the ward and its impact can be easily understood with this simulator. This makes it easier to help them plan and improve the ward medical facilities in challenging times like the pandemic. The thirteen features that are used to predict the risk score of the ward can be divided into three categories - static, user inputs, and forecasted inputs.

1) Data inputs:

- *Static inputs*: Publicly available ward information like - ward area, number of houses, number of literates, number of children below age 6, working population, and average family size in the wards is collected from the data sources provided by the government [15].
- *User inputs*: Additional number of beds and hospitals that are to be added in a ward are taken as input from the user.
- *Forecasted inputs*: Informed estimates on the parameters like the hotspots and AQI of the ward that varies with time are forecasted using Prophet model [16].

2) Modelling the Simulator: Appropriate data collection, data preparation, analysis and pre-processing, model training, and testing using thirteen features are done to build the risk model. Data for training the model is collected daily from the previously mentioned sources. First, a pipeline is created, and a job is scheduled for periodic data collection. Data is

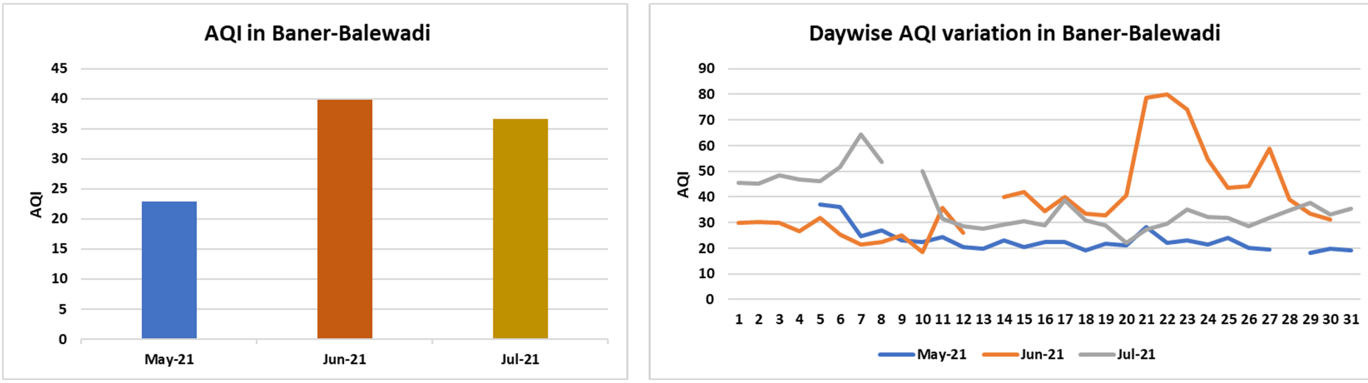

Figure 9. AQI variations in Baner-Balewadi during Phase 2

TABLE V
AQI AND ITS PARAMTER VARIATIONS ACROSS THE STUDY PERIOD

	Mar20	Apr-20	May-20	Jan-21	Feb-21	Mar-21	May-21	Jun-21	Jul-21
AQI	132.42	100.67	85.27	115.27	102.64	97.04	72.54	71.11	68.39
Sound	61.99	55.81	55.29	70.45	72.30	72.25	72.61	72.46	73.29
NO_2	69.57	41.99	42.50	73.47	69.93	58.41	48.33	46.63	43.81
SO_2	2.08	1.13	0.88	2.48	1.73	1.65	1.21	1.39	1.47
$PM_{2.5}$	19.51	10.27	10.14	32.38	15.20	22.37	8.54	9.06	10.36
Ozone	46.30	57.25	47.43	16.16	22.74	35.26	32.62	24.23	22.86

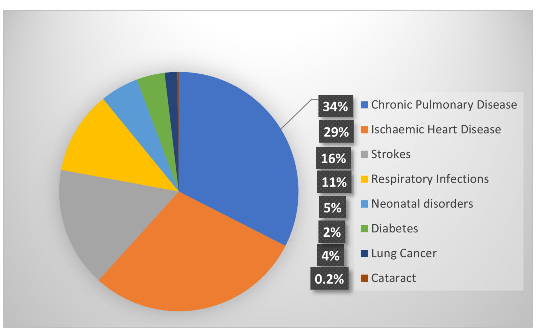

Figure 10. Causes of Deaths attributable to Air Pollution in India in 2019.

TABLE VI
FEATURES USED TO CALCULATE THE COVID-19 RISK SCORE

Feature#	Feature Name
1	Health Score
2	Houses
3	Literate Population
4	Population under 6
5	Family Size
6	Working Population
7	Hospitals
8	Oxygen beds
9	Beds without oxygen
10	ICU ventilator beds
11	ICU beds without ventilator
12	Additional beds
13	Hotspots

collected from all the above-mentioned data sources on a day-to-day basis. This is followed by data pre-processing, data aggregation, and model building. In the pre-processing step, the geo-coordinates and addresses available in the collected data are mapped to appropriate ward IDs using geocoding and mapping techniques. Further, in the data aggregation step, based on ward IDs the data is aggregated at the ward level. Data is cleaned and the missing values are imputed with appropriate techniques. This data is used to train the risk score prediction and simulator model. With the help of the risk score, users (city authorities, planners so on) can categorize the wards into various levels of risk and further select the ward to see how the risk score varies with changes in the current ward medical infrastructure facilities. The risk score initially calculated by the model is used as the reference (R). Using the simulator tool, they can understand and analyze the impact of incremental variations in the ward facilities like the number of beds (x) and hospitals(y) over the risk score during the analysis period. The tool can also help users make decisions on further improving the current ward medical infrastructure facilities. Figure 12 shows the user interface for the simulator tool.

As a first step, a user selects the ward and based on the existing data, the model predicts the risk score (R) of the ward. The initial details are shown in the table on the screen. With this as the reference, the user can fine-tune the input parameters like the number of beds(x1) and hospitals(y1) to be further added under the parameter fine-tuning section to get the new risk score (R1). In the backend, for the selected ward, the simulator tool collects the static data (Features 2,3,4,5,6) from the database. Further, using the previously available data for

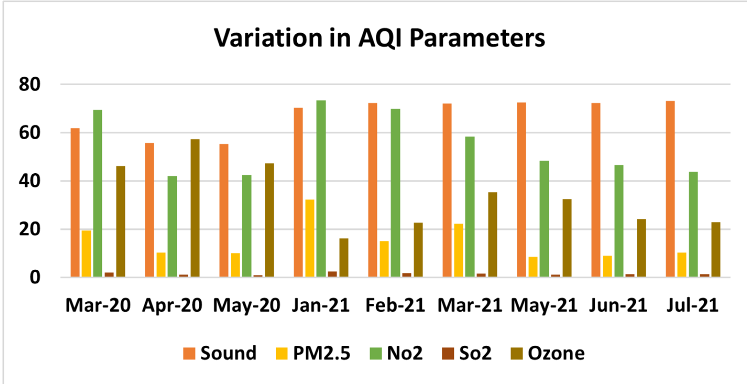

Figure 11. Variations in AQI Paramters

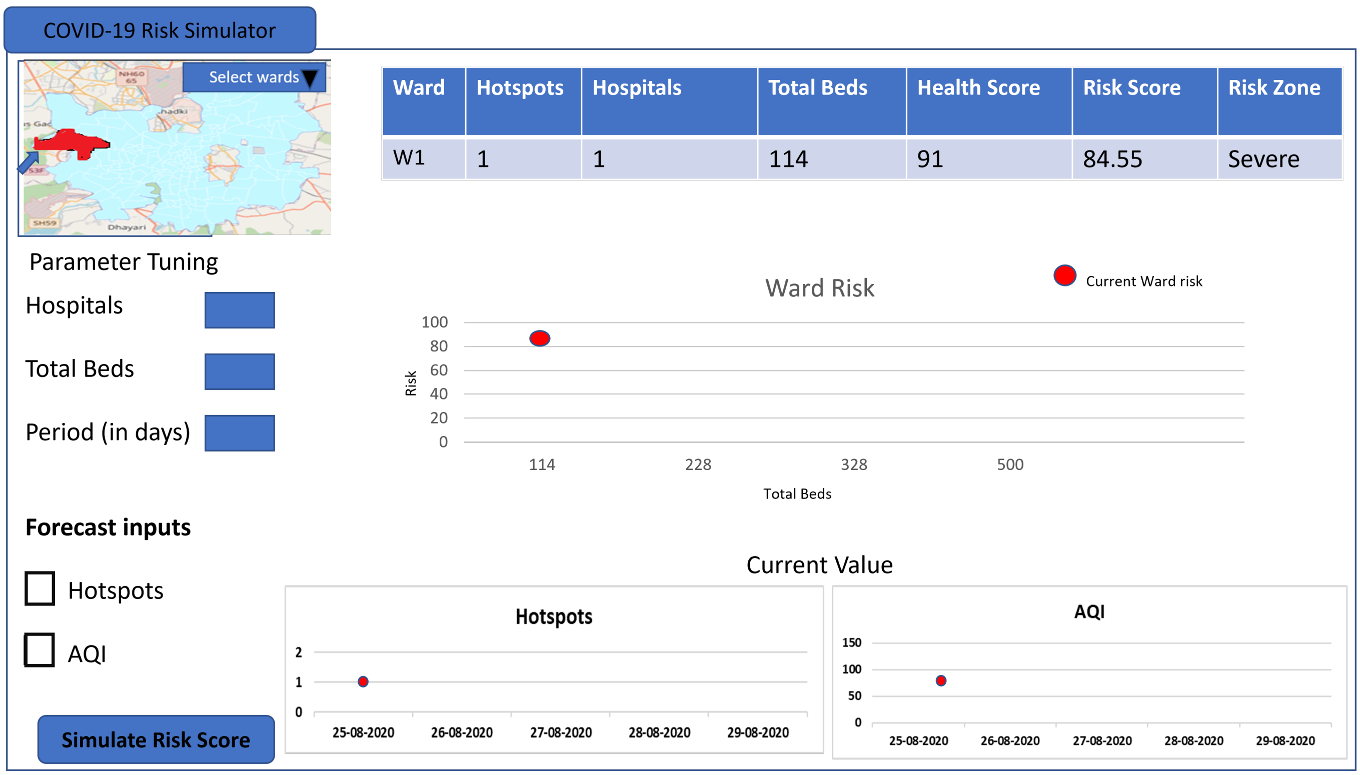

Figure 12. Landing page of the simulator tool

the ward, the tool forecasts the value for the features (Features 1 and 13) for the entered date using the Prophet model. The accuracy of the forecasting model is validated with the actual data for a few wards as shown in Table VII. Using these inputs, the tool predicts the new risk score for the entered inputs. Figure 13 shows the simulated risk scores. Table VIII shows how risk scores for a few wards changed with the change in input features.

From the predicted risk scores, it is evident that the potential risk level of the wards can be reduced by improving the ward medical infrastructure facilities (number of beds, hospitals). In most of the wards, increasing the ward facilities resulted in a change in the ward risk zones. However, it must be noted that no single attribute or feature can individually explain the measure of ward risk. Therefore, using this tool, the user can vary the inputs related to the number of beds and hospitals that can be added to the ward and precisely understand how it impacts the risk score. Users can accordingly increase the value of the input features till the ward risk reduces to an acceptable level. This type of impact analysis in turn assists the authorities to make informed decisions to increase the medical infrastructure facilities in the ward during the pandemic.

IV. Discussion of Results

In our work, we analyzed the AQI and the ward level COVID-19 risk score for PMC-Pune in detail during the

TABLE VII
ACCURACY OF THE FORECASTING MODEL

Ward	Date	Forecasted AQI	Actual AQI	Forecasted Hotspot	Actual Hotspot
47	20-11-2020	113.89	128.69	3	3
47	21-11-2020	113.11	113	3	3
47	22-11-2020	115.29	113	3	3
47	23-11-2020	113.44	113	3	3
47	24-11-2020	118.50	129.5	3	3
144	20-11-2020	135.11	146.13	2	2
144	21-11-2020	139.14	146	2	2
144	22-11-2020	135.06	146	2	2
144	23-11-2020	143.90	146	2	2
144	24-11-2020	139.28	127.67	2	2

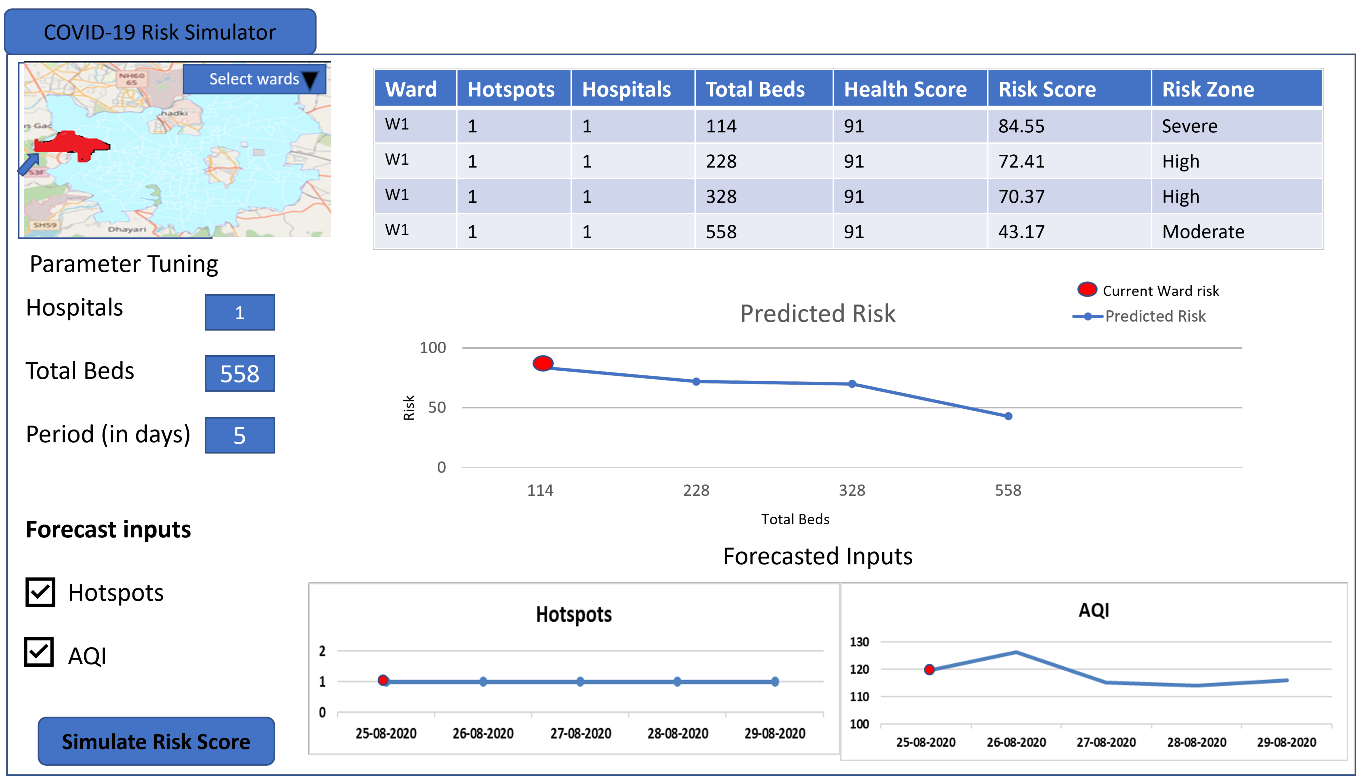

Figure 13. Ward risk analysis with the simulator tool

TABLE VIII
BEDS AND SIMULATED RISK SCORES

Ward	Population	Health Score	Beds	Risk Score	Risk Zone
Vishrantwadi	24678	91	114	84.55	Severe
Vishrantwadi	24678	91	228	72.41	High
Gokhlenagar	14614	75	81	64.29	High
Gokhlenagar	14614	75	160	54.71	Moderate
Bopodi	15834	59	60	78.26	High
Bopodi	15834	59	120	64.06	High
Dhanori	44060	91	43	86.66	Severe
Dhanori	44060	91	86	80.03	High
Koregaon	14685	82	248	42.57	Moderate
Koregaon	14685	82	496	34.21	Low

pandemic. AQI information was collected from air sensors deployed across the city and mapped to their respective wards. During Phase 1, 29 of the 34 wards showed improvement in the AQI levels. This improvement was majorly seen due to the strict lockdown rules imposed across the country to limit the movement of the population. While 21 out of 26 wards and 15 out of 31 wards showed improvement in the AQI levels during the Maintenance Phase and Phase 2, respectively. The surge in the AQI levels can be associated with the minimal restrictions during the unlock phases in the country, increased vehicular movements, increased energy consumption, and an increase in industrial operations related to the production of essential supplies. The significant decrease in certain parameters across the months can be attributed to nationwide lockdown, implementation of protocols, and other precautionary measures taken by the people during the pandemic to curb the COVID-19 cases across the country. Overall, AQI varied by 48%, sound by 18%, Ozone by 51%, NO_2 by 37%, SO_2 by 29% and $PM_{2.5}$ by 47% from March 2020 to July 2021.

Further, the simulator tool introduced in this paper forecasted the dynamic parameters like the AQI levels in the ward with 94.5% accuracy. Along with the user inputs, these forecasted values were used to simulate the risk scores of the wards. From the simulator results, the impact of improving ward-level medical and infrastructural facilities and its association with the ward risk score became evident. This tool not only helps authorities foresee hotspots or AQI levels in the wards over days, and categorize wards based on their risk levels but also helps them make informed decisions on incremental improvements in the ward medical and infrastructure facilities during challenging situations like the pandemic.

V. Conclusion and Future Work

This paper provides an in-depth Spatio-temporal analysis of the AQI levels of the wards in PMC-Pune. Since our study is done at a granular ward level, with such analysis it becomes easier for authorities and city planners to take action in improving the overall environmental health and living conditions of the city. The study highlights how the air quality and other air pollutants varied in the wards over the months in PMC-Pune during the pandemic. With the imposition of restrictions, the wards saw significant improvements in the AQI. Thus, it advocates the need to improve the overall environmental health conditions of the wards in the city. Further, the simulator tool introduced in this work, helps authorities foresee and understand the impact of the risk score in the ward with incremental variations in the ward facilities during the pandemic. City planners can use this tool to assess and estimate the required increase in the ward medical facilities that would bring in a reduction in the ward risk score. Thus, this tool acts as an aid that assists city planners in their ward planning activities. When the overall condition of the ward improves, its ability to handle situations like the pandemic increases. With better facilities, the living conditions in the ward can improve and the ward can gradually attain self-sufficiency. Overall, this paper is based on the data available in PMC-Pune. However, the same can be extended to other smart cities where similar data is available.

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Population Generation for Agent-based Simulations of Stroke Logistics Policies

A Case Study of Stroke Patient Mobility

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***Abstract*—For acute medical conditions, for instance strokes, the time until the start of the treatment is a crucial factor to prevent a fatal outcome and to facilitate the recovery of the patient's health. Hence, the planning and optimization of patient logistics is of high importance to ensure prompt access to healthcare facilities in case of medical emergencies. Computer simulation can be used to investigate the effects of different stroke logistics policies under realistic conditions without jeopardizing the health of the patients. The success of such policies greatly depends on the behavior of the individuals. Hence, agent-based simulation is particularly well-suited as it imitates human behavior and decision-making by means of artificial intelligence, which allows for investigating the effects of policies under different conditions. Agent-based simulation requires the generation of a realistic synthetic population, that adequately represents the population that shall be investigated such that reliable conclusions can be drawn from the simulation results. In this article, we propose a process for generating an artificial population of potential stroke patients that can be used to investigate the effects of stroke logistics policies using agent-based simulation. To illustrate how this process can be applied, we present the results from a case study in the region of Skåne in southern Sweden, where a synthetic population of stroke patients with realistic mobility behavior is simulated.**

Keywords-Agent-based Simulation; Synthetic Population; Population Generation; Policy Making; Mobile Stroke Unit.

I. Introduction

Certain medical conditions, for instance strokes, require rapid responses of medical professionals to prevent a fatal outcome and to facilitate the recovery of the patient's health. However, many victims of potentially life-threatening conditions such as strokes are often not surrounded by medical professionals when these conditions occur as they may appear suddenly and without prior indications. Accordingly, to prevent permanent damage from such acute medical conditions or even the patients passing away, it has become a goal of our society to provide adequate care to all citizens as quickly as possible. This includes the development of an advanced medical infrastructure that provides necessary health care services but also to ensure that this infrastructure is available for everyone. Some treatments of medical emergencies, however, require specialized equipment and personnel, which is only available in certain facilities (e.g., specialty hospitals). Especially in rural areas, there is a lack of such facilities. Hence, the planning and optimization of patient logistics is of high importance to ensure prompt access to healthcare facilities in case of medical emergencies.

In a study presented at the *IARIA DIGITAL 2021* conference on *Advances on Societal Digital Transformation*, Alassadi et al. [1] address the challenge of generating a realistic population of stroke patients, which takes travel behavior into account. Such an artificial population of stroke patients is required, for instance, in agent-based simulations (ABS) and allows for the assessing the effects of different stroke logistics policies. One example of such a policy is the optimal placement of Mobile Stroke Units (MSUs) across a region. The study uses aggregated and individual-based data from different sources, from which probability distributions can be derived to generate an artificial population of agents.

In their study, the authors focus on strokes, which is a common cause of mortality [2]. Every year, more than 1 million people in the European Union suffer from a stroke and the one-month case-fatality is up to 35% [3]. The occurrence of strokes is associated with the age of the individual and most of those suffering from a stroke are 70 years of age or older. Hence, as the number of people that are older than 70 years will increase, the number of strokes is also expected to increase [4], [5].

To investigate the suitability and effects of different stroke logistics policies for a specific region, computer simulation can be used. They allow for investigating different policies under realistic conditions without jeopardizing the health of the patients. Instead of conducting real-world studies, different policies and their potential effects can be studied and compared in an artificial system. To this end, simulation enable *what-if* analyses of different scenarios, to analyze how different circumstances affect the behavior of a system without actually interfering with the real-world system that shall be investigated.

The use of simulation in healthcare is well established. Barnes et al. [6], for instance, provide a comprehensive overview of how simulation can be applied in healthcare operations management and underline the successful application of simulation for evaluating policy alternatives. An increasing application of simulation in healthcare has also been identified by Almagooshi [7], e.g., for the analysis of patient flows, emergency departments, and treatment of, e.g., stroke.

The effects and success of logistics policies greatly depends on the behavior of individuals that are affected by the policy. Hence, to investigate how different policies affect the accessibility to healthcare services for patients, the behavior and routines of the potential patients need to be represented in the simulation model. We argue that ABS is particularly well-suited to investigate the effects of logistics policies, not only in terms of strokes but also for other acute medical conditions.

In ABS, an artificial population is generated, which consists of so-called *agents*. Agents are characterized by individual attributes such as age, gender, place of residence, and health state, and imitate human behavior using Artificial Intelligence. A major challenge when using ABS to analyze logistics policies, for instance for the treatment of strokes, is the generation of an artificial population of patients that imitate the behavior of the real-world population such that the effects of the policies can be investigated. This might include deterioration of health condition according to individual attributes such as, e.g., age, gender, but also the modeling of the patients' whereabouts. For instance, when investigating the placement of MSUs for the treatment of strokes, the locations of the MSUs should be determined such that the time to treatment can be reduced for all inhabitants of the region. For this purpose, Amouzad Mahdiraji et al. [8] studied the average time to treatment for different distributions of MSUs and showed that a small number of MSUs can indeed significantly reduce the time to treatment for most inhabitants in the region. For their study, the authors used demographic data on the inhabitants' place of residence for determining where the demand for emergency care occurs. However, this does not consider that individuals travel and might not be at home when having a stroke, for instance, due to leisure activities, shopping, or work. Yet, the spatial distribution of strokes potentially affects the suitability of different stroke logistics policies and, thus, might need to be considered when assessing their suitability.

In this article, we propose a process for generating an artificial population of potential patients that can be used to investigate the effects of stroke logistics policies using ABS. To illustrate how this process can be applied, we present the results from a study where a synthetic population of stroke patients with realistic mobility behavior is simulated. We apply the model to the region of Skåne in southern Sweden to investigate how travel behavior is expected to affect the spatial distribution of stroke patients. The proposed approach allows for testing different policies without jeopardizing the health of the patients. The generated synthetic population of stroke patients can be used, for instance, to assess different logistics policies, e.g., to compare different placements of MSUs and to assess how this affects the time to treatment. The process, however, is not only applicable for stroke patients but can also be adapted and applied for other acute medical conditions.

The remainder of the article is structured as follows. Section II presents related work on the use of agent-based modeling and simulation in healthcare, on policy making for treatment of acute strokes, and on methods for population generation. In Section III, the process for generating a synthetic population is presented. In Section IV, a case study is presented where the proposed process is applied for generating a population of stroke patients with travel behavior. Section IV presents and discusses the results of the case study in Skåne, Sweden, and in Section V, conclusions are drawn, and future work is presented.

II. Background

Diagnosis and treatment processes in healthcare often include multiple consecutive steps and involve different specialists and caregivers. Planning and optimizing such complex processes are challenging and requires the comparison of potential configurations under different circumstances. Evaluating these processes in the real-world prior to their implementation might not only be costly and time consuming but also pose a danger to the patients' well-being. To overcome this, simulation can be used. By building a virtual model of the real-world, an artificial system can be created to investigate different scenarios and to observe the effects different measures and decisions might have on the process of care provision.

A. Agent-based modeling and simulation in healthcare

There exist different simulation paradigms, i.e., approaches for modeling and simulating phenomena or systems. In healthcare, as well as in other domains where humans are the object of investigation, individual-based simulation paradigms are often applied. An example is ABS, a form of microsimulation, which consists of the simulation of states and behavior of individuals over time [9]. Here, each individual is represented by an agent, an autonomous entity that, for example, imitates human-like behavior and reasoning. This includes the subjective perception of the environment but also the individual decision making based on the personal traits and characteristics of each individual, which leads to individual actions and behavior.

In logistics and production, for instance, the use of simulation is well established [10]. But also in healthcare, for instance in terms of the ongoing Covid-19 pandemic, the use of simulation is feasible [11]. Cabrera et al. [12] use simulation for designing a decision support system that can provide management support for emergency departments. This is achieved by analyzing the optimal staff configuration to minimize patients' waiting time and maximize patient throughput. A more extensive simulation model of hospital processes has been proposed by Djanatliev & German [13]. It combines individual-based simulation with system dynamics for analyzing different innovative workflows prior to their implementation, e.g., prostate cancer screening and effects of MSUs on onset-to-treatment times.

Simulations of stroke treatment were presented by, for instance, Monks et al. [14] and Chemweno et al. [15]. Monks et al. investigate clinical benefits of reducing delays in thrombolysis (alteplase) of AIS patients. They propose a discrete-event simulation model of stroke patients arriving at a large district hospital, where measures can be adopted to reduce in-hospital delays (e.g., prealert of paramedics) and where certain limitations of alteplase treatment (i.e., extension of treatment deadline from 3 to 4.5 hours and patient age over 80 years) can be relaxed. To assess and compare the benefits of policies for reducing waiting times, the authors model two treatment paths, the traditional treatment and one that takes measures into account for reducing in-hospital delays. The results show that an extension of the time window in combination with reduced delays can lead to 5-times increased thrombolysis rates. Chemweno et al. present a discrete-event simulation of the diagnostic path of patients in a stroke unit to investigate the effect of different test capacities. This is to overcome shortcomings of traditional queuing theory models, which cannot predict waiting times due to the complexity of treatment pathways and interrelationships between required resources. This allows for the assessment of policy changes in capacity profiles and test resources. The study outlines the effects different policies might have on waiting times, e.g., adding extra timeslots, shifting from MR to CT scans, and implementing joint timeslots.

B. Agent-based Simulations for Policy Making

Even though the use of agent-based approaches is established in many domains and disciplines, the practical use to facilitate policy making is still limited. Most applications pursue scientific purposes, which might be due to a series of reasons, e.g., lacking trust in the models or inappropriateness of models, difficulties in developing or using the models, and a lacking awareness that the method exists.

Ruppert et al. [16] argue that a thorough analysis of policy options is required before a suitable policy can be implemented. To this end, they argue that ABS often are complex and, thus, difficult to access by policy makers. Silverman et al. [17] underline that simulations are essential to address population health challenges, as they complement traditional epidemiological toolkits. They particularly outline that additional data sources need and especially GIS information need to be integrated such that models can serve as policy sandboxes and that ABS can become a valuable tool for healthcare-related policy making. By proposing a process for generating an artificial population of patients that can be used in ABS, we contribute to lowering the threshold for using simulation in policy making.

C. Policies for Treatment of Acute Strokes

What makes the example of strokes particularly well-suited for studying patient logistics policies is that there are two types of acute strokes. Acute ischemic strokes (AIS), where a clot or narrowed blood vessel blocks the flow of blood to the brain, and hemorrhagic strokes, caused by a burst blood vessel [18]. Both types of strokes require immediate treatment and delays negatively affect the patients' outcomes. Yet, the treatment of these two kinds of strokes differs greatly. To dissolve the blood clot and to restore the blood flow, an AIS needs to be treated with thrombolytic medication as quickly as possible. In case of hemorrhagic strokes, however, there is a contraindication for thrombolysis as it might kill the patient. Instead, the effect of blood thinners must be counteracted to control and stop the bleeding. Hence, making the right diagnosis is a vital first step for the efficient treatment of strokes.

Imaging of the brain, e.g., through CT or MRI scans, and specific laboratory tests are required to adequately diagnose the cause of a stroke. However, especially in urban areas, the access to such scanners and laboratories is limited and the patient needs to be transported to a suitable hospital, causing valuable time to pass. A stroke logistics policy that can be applied to address this challenge is the deployment of Mobile Stroke Units (MSUs), which are specialized ambulances with all equipment required to diagnose stroke patients. Through this, the time between the onset of symptoms and the beginning of treatment of the stroke can be shortened, which significantly can improve the prognosis of the patients. The feasibility of this concept and its capability to prevent brain damage of stroke patients was demonstrated by Walter et al. [19].

For the treatment of acute ischemic strokes, intravenous thrombolysis to dissolve the blood clot is the only approved reperfusion treatment [20]. However, according to Fassbender et al. [21], only less than 5% of the stroke patients receive this therapy. One potential explanation is that the critical time window of 3 hours is exceeded due to the transport to the hospital. To reduce the time to treatment, the use of Mobile Stroke Units (MSUs) was proposed, i.e., specialized vehicles that are equipped with devices required for adequately diagnosing and treating stroke patients. Walter et al. [19] compared the use of MSUs to hospital treatment and found that the time from alarm to therapy could be reduced from 76 to 35 minutes. Calderon et al. [22] analyzed the worldwide status of MSUs and compared different services outlining the success of the approach. The economic viability of MSU treatment was analyzed by Kim et al. [23], underlining its cost-effectiveness due to earlier provision of therapy.

The success of MSUs and their effect on treatment times also depends on where they are located. Rhudy et al. [24] visually analyzed data of MSU dispatches and the occurrence of strokes to optimize service provision. For Sydney, Australia, Phan et al. [25] searched for optimal locations for MSUs by investigating travel times from suburbs to each potential MSU hub. For a similar purpose, Amouzad Mahdiraji et al. [8] developed an agent-based model that allows for analyzing the benefits of different MSU configurations. In their study, Amouzad Mahdiraji et al. investigated the average time to treatment for different distributions of MSUs and showed that a small number of MSUs can significantly reduce the time to treatment for most inhabitants in the region. Moreover, agent-based simulation can also be used to assess other stroke logistics policies, e.g., whether patients should be brought to the closest hospital or to a specialized thrombectomy center [26]. To assess this, Al Fatah et al. developed a simulation model of logistical operations of stroke patients, i.e., whether patients should be transported to the closest hospital or towards a stroke center. The results showed that those patients that require special treatment indeed benefit from being transported in the direction of a stroke center whereas those who do not require specialist treatment benefit from being transported to the closest hospital.

None of the presented approaches takes travel behavior into consideration when investigating and optimizing locations and service designs of MSUs. Instead, individuals are assumed to stay at their home location, which can be derived from census data or randomly selected using Monte Carlo approaches [26].

D. Population Generation

To generate realistic results when applying agent-based simulation, individuals and their behavior must be modeled in a realistic way. Especially when modeling a larger population of individuals, it is important that the relevant features of the artificial population, e.g., age distribution or employment status, correspond to those of the original population. However, due to privacy reasons, data on each individual's properties is usually not available. The challenge associated with synthetic population generation is that aggregated data, e.g., census data, and disaggregated personal data need to be combined to model each individual, such that the characteristics of the modeled population correspond to the used input data [27], [28]. In transportation, for instance, population generation is used to model individual demand for mobility services [29], [30].

III. Population Generation for Simulating Stroke Logistics Policies

The success and suitability of using ABS for policy making strongly depends on how realistically the behavior of the individuals is modelled. In this regard, it is relevant to use appropriate data and to identify all aspects of human behavior and decision-making that are important for the scenarios that shall be investigated as well as to adequately model them. Especially when using ABS for policy making, simpler models of human behavior can limit the adaptability of the individuals and, thus, limit the significance of the simulation results. This is also in line with the trend from simple and abstract models (KISS approach) to more data-based and descriptive models, taking a wider range of evidence into account (KIDS approach) [31].

Modelling human behavior often includes the use of real-world data, e.g., socio-demographic census data, for generating a realistic population. Chapuis & Taillandier [27] identify two main difficulties when generating synthetic populations, i.e., *expansion* and *harmonization* of available data, and discuss different approaches for generating synthetic populations for ABS. In particular, the authors distinguish between *synthetic reconstruction* and *combinatorial reconstruction*. Synthetic reconstruction is mostly based on probability distributions that the generated individuals need to correspond to whereas the approach of combinatorial optimization is to draw individuals from a sample and to (iteratively) modify this sample until it satisfies a given fitness criterion.

Based on a literature review, Chapuis & Taillandier conclude that population generation processes tend to be poorly described. To overcome this, we propose a process for generating a synthetic population of individuals that can be used to assess stroke logistics policies. To demonstrate the feasibility of this process, we apply it to a case study of stroke patient mobility in Skåne, Sweden.

There exists a number of different approaches for generating synthetic populations that can be used in agent-based simulation models [32]. Some approaches reply on the availability of disaggregated data, from which samples are drawn and optimized. In our study, some of the available data sources contain aggregated data, i.e., census data and stroke data, which is due to data protection reasons.

Thus, we pursue a conventional approach in this study as, for instance, described by Barthelemy & Cornelis [33]. In this approach, aggregated data, that in average describes certain characteristics of the true population, is merged with disaggregated data from a sample to generate a disaggregated dataset of a synthetic population. After identifying all relevant socio-demographic characteristics of the population, the underlying distribution of the true populations' characteristics is estimated such that the distribution of the characteristics is preserved. Following this, individuals are selected from the disaggregated sample and added to the synthetic population in accordance with the estimated distribution. The goal of this approach is not to provide a one-to-one mapping of the real population but a matching of individuals to maintain the distribution of the relevant characteristics and attributes of the original population.

For the assessment of stroke logistics policies, we first need to identify the important aspects of human behavior that need to be included. One determining factor for the prevalence of health conditions is the age of the individual and as we want to analyze logistics policies, the location of the individuals is important as well. Hence, we integrate census, travel survey, and health data to model the occurrence of a medical condition at specific locations.

The presented process is inspired by Bissett et al. [34] and consists of three major steps that gradually add complexity to the synthetic population (see Figure 1). First, all individuals are generated using socio-demographic census data to define the constant attributes, i.e., those that do not change over time such as age, gender, or municipality of residence. Census data is often aggregated on a grid-base, e.g., 1x1 km grid cells. Hence, the grid cells need to be assigned to municipalities using GIS data. These constant attributes are important when using data from different datasets for the population generation as common attributes across the datasets, e.g., age or municipality, are required for the matching process [33].

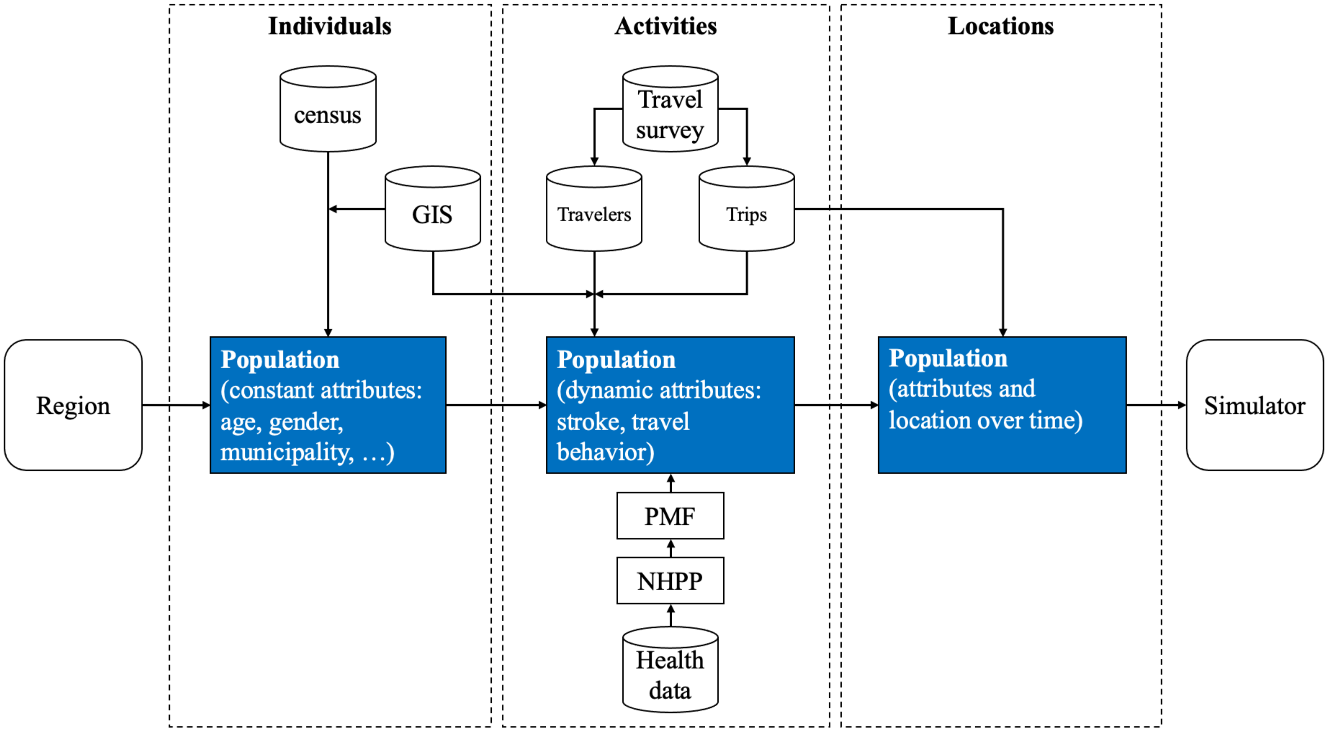


Figure 1. Process for generating a synthetic population of patients for investigating stroke logistics policies.

Individuals are then equipped with activities, which affect personal attributes that change over time, i.e., mobility patterns that affect the individuals' locations and stroke occurrences that affect their health condition. In this step, disaggregated data is used to complement the aggregated census data according to the conventional approach described by Barthelemy & Cornelis. For modeling mobility, travel survey data can be used, that consists of real-world data on travelers (e.g., age and home municipality) and the trips they have taken (e.g., origin, destination, and trip length). Joining this data with GIS data allows for generating time-dependent travel demand between zones of a municipality as well as between municipalities. The second dynamic attribute, which is coupled to the occurrence of a stroke, can be modeled by estimating the probability distribution of strokes from health data such that it can be matched according to age groups and municipalities. This is achieved by means of probability mass functions (PMF) and a non-homogeneous Poisson process (NHPP) (cf. Section IV).

Finally, based on the travel demand, the location of each individual can be calculated over time. This is required to be able to determine where an individual is located when a stroke occurs.

IV. An Agent-based Model for Generating a Population of Stroke Patients with Travel Behavior

To allow for a more dynamic and realistic assessment of health logistics policies, we proposed a process for population generation. The resulting synthetic population can be used as input to an agent-based model to investigate the effects of different policies. In this article, we use the example of stroke patients to show how such an analysis can be performed, taking travel behavior of individuals into account.

In this section, we demonstrate how we generate a synthetic population of potential stroke patients, combining socio-demographic census data, data on real strokes cases from a healthcare provider, and travel data from a transport service provider. This allows for the simulation of the dynamical spatial and the temporal component of stroke occurrence and treatment.

For the study, we selected Skåne, a region in southern Sweden. Skåne consists of approximately 1.4 million inhabitants, that live in 33 municipalities with a total area of nearly 11 000 km^2. In Skåne, there are 9 hospitals with emergency departments that can treat acute strokes. In 2015, there were 3 973 stroke incidents recorded in Skåne, out of which 3 830 patients also live in Skåne. Moreover, 12 patients that have their place of residence in Skåne were treated in the neighboring counties Kronoberg, Blekinge, or Halland and most of the patients are 45 years of age and older. Based on data from the regional healthcare provider, *Södra Sjukvårdsregionen* (Southern Health Care Region; SHR), we derived the daily distribution of strokes per hour (see Figure 2). Most strokes are reported during the afternoon with most of the incidents occurring around 4 p.m.

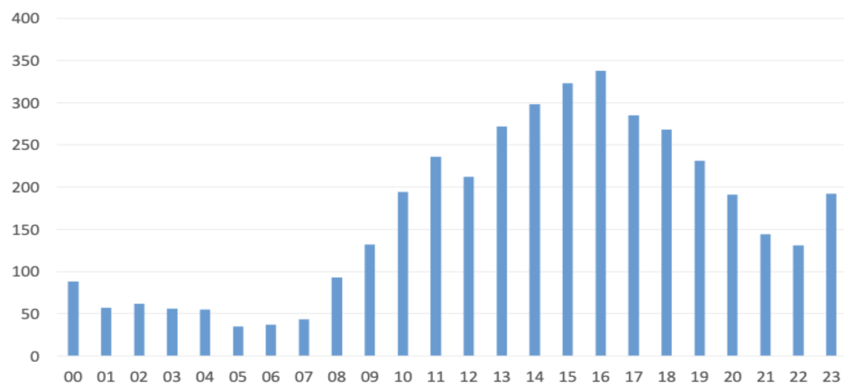


Figure 2. Total number of strokes per hour extracted from data of the regional healthcare provider.

To model travel behavior, we used data from a regional travel survey (*Resvaneundersökning för Skåne; RVU*) that was conducted in Skåne in 2013 [35]. As part of this study, travelers were asked about their traveling habits and the resulting dataset contains information on approximately 56 000 distinct trips. This includes, for instance, the origin, destination, duration, and purpose of the trip but also socio-demographic data on the travellers, e.g., age, gender, and place of residence.

Finally, for generating a realistic population, we used a census dataset from *Statistiska centralbyrån* (Statistics Sweden; SCB), the Swedish government agency for statistics. The SCB dataset includes, for instance, information of the density and age of the population of Skåne. Yet, this data only provides information on the permanent residence of individuals and not on their actual location. To allocate the anonymized trips of the RVU dataset to actual individuals from the SCB dataset, we randomly match the datasets based on the individuals' age group and home municipality.

For modeling the inter-arrival time of stroke incidents, we used a non-homogeneous Poisson process (NHPP) [36]. In contrast to ordinary Poisson processes, that are used to model events that occur with a fixed average rate of arrivals (λ), the rate of arrivals can vary over time in an NHPP where $\lambda(t)$ is the rate function for time segment t for all $t \in [0, t_0]$ and $\lambda_u(t)$ is the maximum number of actions in a time series with $0 \leq \lambda(t) \leq \lambda_u(t)$. By this means, we can explicitly model the accumulation of stroke events during the afternoon. In our NHPP, we divide each day into 24 time segments, each equipped with a specific probability that a stroke occurs during this hour in relation to the number of strokes occurring per day.

Based on the generated number of daily stroke incidents, we define two probability mass functions (PMF) to distribute strokes across age groups and municipalities. These two distributions are then used to generate stroke incidents. Each generated stroke event consists of the patient's age group, municipality, day of the year, and time of the day. This dataset is then matched with the population dataset, to predetermine the stroke patients as well as the point in time when the stroke will occur.

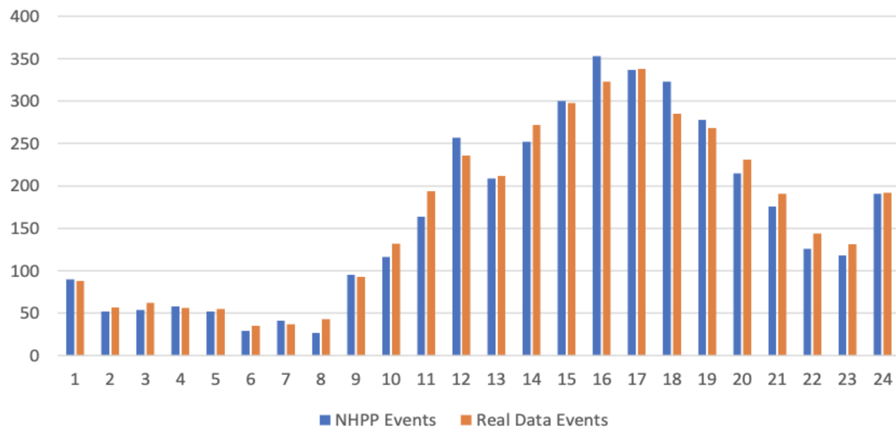
When executing the model, the travel behavior, i.e., each trip of an individual, and the resulting locations of each individual of the population is simulated over time. The generated NHPP events define when the individual stroke incidents occur, and, at the generated time of each stroke incident, the individual's current location can be determined based on the simulated trips.

In recent years, ODD (Overview, Design concepts, and Details) protocols have been used to describe the structure and the dynamics of agent-based models in a standardized document [37]. They provide more detailed insights into the model and the underlying assumptions, which can be relevant for the interpretation of the results as well as for replicating experiments. The ODD of the model presented in this article can be found in [38].

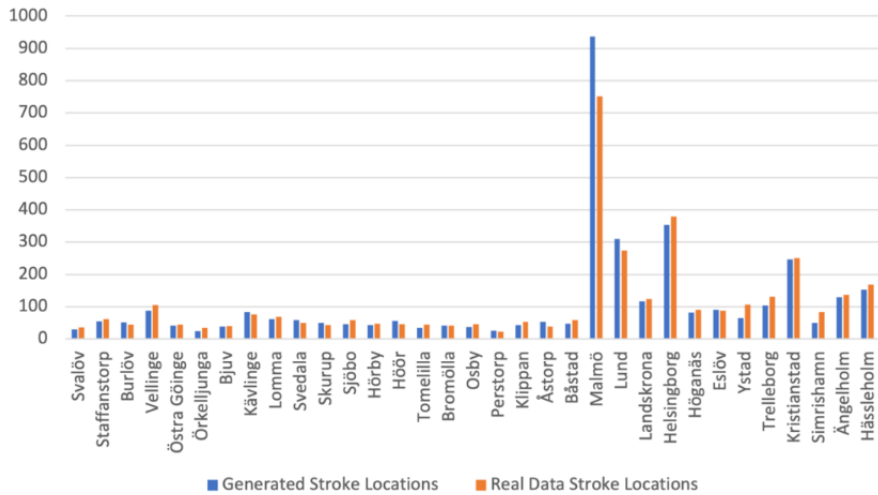
V. RESULTS OF THE SCENARIO STUDY IN SKÅNE

We implemented the agent-based model of stroke patient travel behavior in the *Repast Simphony* simulation framework [39]. In the simulation, each time unit (tick) corresponds to 1 minute in reality. Hence, each day is simulated as 1440 ticks. For each tick, it is determined whether an individual will go on a trip and move to another location. When the predetermined stroke events occur, it is checked whether the individual is on a trip, to determine where the stroke occurred.

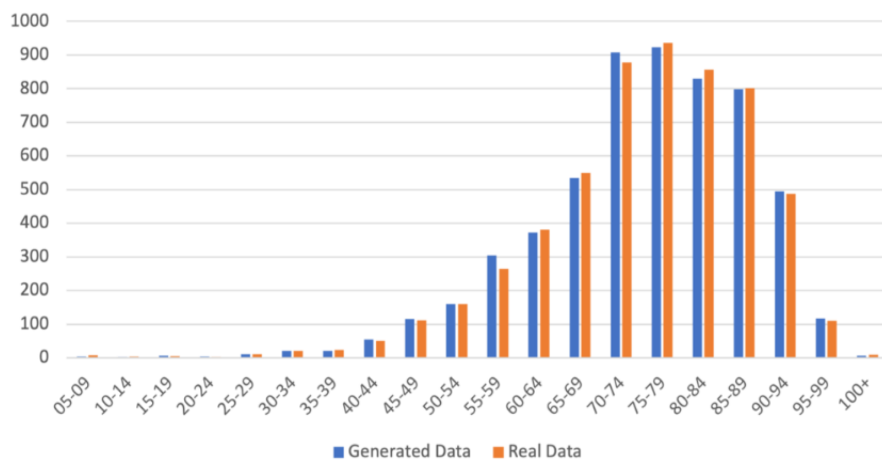
The probability distributions that we extracted from the dataset are shown in Figure 3. The charts show the real data (orange) in comparison to the NHPP events we calculated (blue). There are only minor deviations from the original data for the stroke incidents per hour, per municipality, and per age group. To quantify how well the artificial data replicates the original data, the Relative Squared Error (RSE) and Root Relative Squared Error (RRSE) are given as measures. No significant deviation of the generated data from the real data can be observed considering the hour of the day (RRSE: 0.160) and the age group (RSSE: 0.046).



(a) hour of the day (RSE: 0.026, RRSE: 0.160)



(b) municipalities in Skåne (RSE: 0.067, RRSE: 0.259)



(c) age group (RSE: 0.002, RRSE: 0.046)

Figure 3. Distribution of stroke incidents: (a) per hours of the day (b) per municipality in Skåne (c) per age group. For each distribution, the Relative Squared Error (RSE) and Root Relative Squared Error (RRSE) are given as measures of the quality of the generated data.

Only for the municipalities in Skåne, a difference can be observed for Malmö (RRSE: 0.259). This might be due to a bias, which results from Malmö's role as center of the region and as the city has notably more inhabitants compared to all other cities and municipalities in Skåne.

Instead of simulating all inhabitants of Skåne, we only simulated the trip activities of those individuals that were predetermined to suffer from a stroke. This is to reduce the computational complexity of the simulation. To reduce the effect of stochastic variations in the results, we replicated the simulation five times and calculated the average values from these runs.

On average, 3 912 strokes occur in our simulation. The results indicate that 3 839 (98.1%) strokes occur at home whereas 73 (1.9%) strokes happen while the individual is on a trip and at another location. To check the plausibility of these results and to validate the study, we compare them to existing data. In the RVU travel data, only 15% of the recorded trips are performed by individuals that are 65 years of age or older, the main risk group for suffering from a stroke. Out of these trips, only 35% are taken in the afternoon, which is the time of the day where the occurrence of a stroke is most likely.

Moreover, we analyzed the dataset of stroke incidents from SHR. Out of 3 842 stroke incidents of patients that live in Skåne, which were recorded within SHR, 3 830 actually got their treatment in Skåne. 3 106 (80.84%) of the patients that got a treatment in Skåne also got it within their municipality or at the hospital that is responsible for their municipality. Out of the remaining 736 patients (19.16%) that did receive their treatment at another hospital, 497 patients live in municipalities where the responsible hospital does not provide emergency services around the clock. Of the remaining 239 patients, 80 were treated at Skåne University Hospital, which also provides highly specialized treatments for severe cases, 57 received treatment at private facilities, whose exact location is unknown, and 59 were treated at a hospital in a neighboring municipality, which might be due to the patients living closer to the hospital in the neighboring municipality. In total, only 46 patients (1.2%) receive their treatment obviously outside their home municipality, where it can be assumed that they were traveling. This corresponds to the results of our simulation.

Figure 4 provides a visualization of the simulation results across the simulated region, Skåne. The occurrence of strokes is shown using a heatmap where the intensity of the red color indicates a higher (denser) occurrence of stroke incidents whereas brighter or completely white areas indicate that less strokes occurred or that no strokes occurred at all. Overall, the shape of the heatmap corresponds to the distribution of inhabitants across the region. In the larger cities, an accumulation of strokes can be observed (e.g., the Malmö-Lund area in the south-western part of Skåne) as well as around other larger cities such as Helsingborg (northwest), Kristianstad (northeast), as well as Trelleborg and Ystad (southern coast).

The crosses indicate the location of the hospitals. It can be observed that there are some accumulations of strokes in the central part of Skåne (Höör and Hörby) as well as in the eastern (Simrishamn) and northern (Osby and Örkelljunga) parts of the region, which do not have hospitals close by. It is in particular such areas that are dependent on sophisticated logistics policies and that can, for instance, benefit from the availability of MSUs.

Figure 5 complements Figure 4 and shows a more detailed view on the Malmö-Lund area. On the left-hand side, the heatmap of this area is shown and each red dot represents one 1x1 km grid cell as defined by the census data used for the population generation process. On the right-hand side, an ordinary map of the same area is shown. Especially in the densely populated areas of Malmö close to the seaside but also in Limhamn (west), Oxie (center), as well as Arlöv, Lomma, and Staffanstorp (north), an accumulation of stroke incidents can be observed. This underlines the plausibility of the generated stroke incidents and shows that the distribution of the occurrences corresponds to the actual residences of the population.

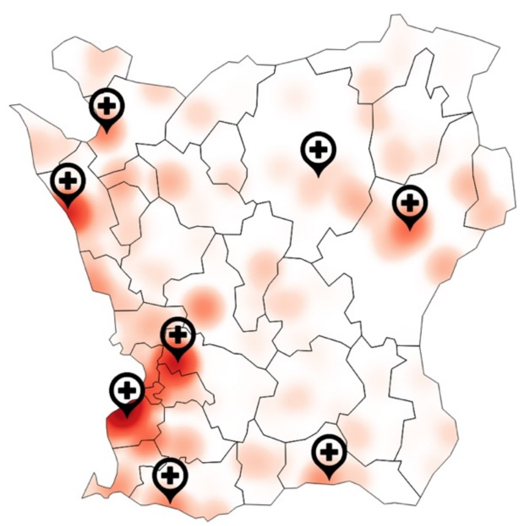


Figure 4. Heatmap of where strokes occur and locations of the hospitals that provide treatment for stroke patients.

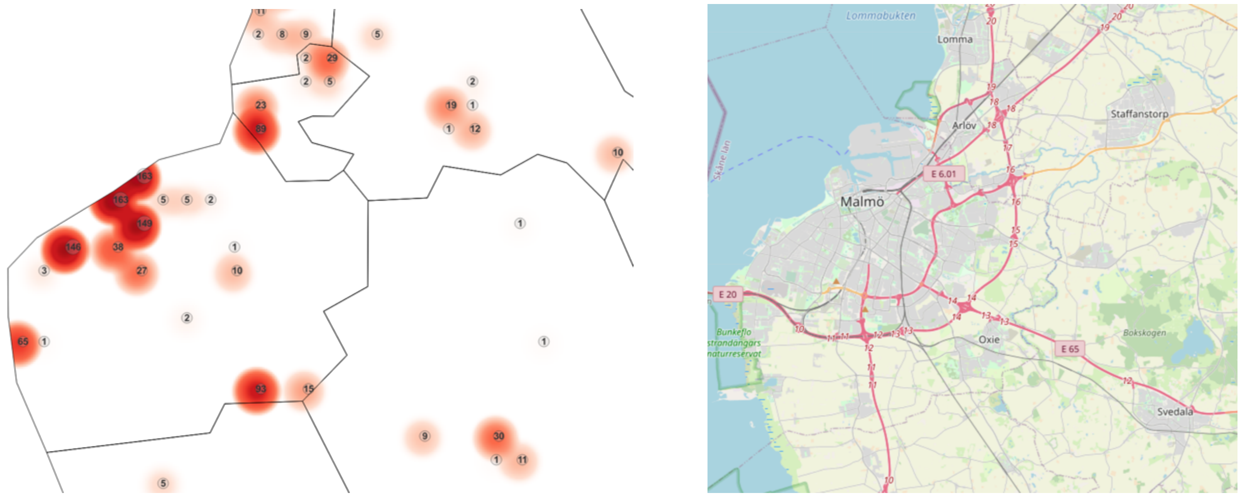


Figure 5. Heatmap of where strokes occur in and around Malmö municipality (left) and OpenStreetMap of the municipalities (right).

VI. Conclusions

In this article, we propose a process for the generation of synthetic populations, which can be used for investigating the effects of stroke logistics policies. The synthetic population corresponds to the original population in terms of the distribution of their relevant attributes that are required for analyzing a particular health condition, in this case, of stroke patients. This includes the age of the individuals, their place of residence (municipality) but also the imitation of their travel behavior as well as of the occurrence of strokes. Such synthetic populations enable the use of ABS, a simulation paradigm that uses Artificial Intelligence for modelling human behavior, which is a crucial factor when investigating the effects of policies.

In particular, we demonstrate the generation of a realistic population of stroke patients, which also takes travel behavior into account. This allows for the assessment of different stroke logistics policies, such as the optimal placement of MSUs across a region. For this purpose, we used aggregated and individual-based data from different sources, from which we derived probability distributions that were then used to generate an artificial population of agents.

To demonstrate the feasibility of the presented approach, we used data from the region of Skåne in southern Sweden. In the presented study, we simulated the travel behavior of stroke patients to investigate where strokes occur. Through this, a better understanding of the spatial distribution of stroke occurrence is achieved. This is relevant, for instance, for the optimal distribution of MSUs, such that the time to treatment is reduced for stroke patients.

Our results show that the generated artificial population corresponds to the real data in terms of the time of the day, at which strokes occur, the distribution of strokes across the municipalities, and the age group of the patients. In total, approximately 1.9% of the strokes occur while the individual is on a trip and not in their municipality of residence. This observation corresponds to data on strokes that was provided by the healthcare provider. Hereby, were able to show by means of simulation that traveling only has a minor impact on where strokes occur and, thus, for policy making in stroke logistics.

The generated artificial population of stroke patients is based on socio-demographic, healthcare, and travel data of the investigated region, to ensure the realistic representation of the real-world population. Yet, the presented process of population generation can also be applied to other regions and for other medical conditions, assuming that the required input data is accessible. This facilitates the conducting of agent-based simulation studies for investigating the effects different stroke logistics policies might have. It also increases the credibility of the simulation results such that conclusions can be drawn regarding the real world.

As part of future work, we plan to incorporate the results from the population generation into simulations for assessing and comparing different policies for stroke logistics. Moreover, we intend to investigate and include seasonality effects into the model, i.e., tourists that come to the region and changed travel behavior during weekends.

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Individualized Self-Care for Early-Stage Dementia: A Framework for Activity Attainment and Replacement

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Abstract— **For people with early or moderate dementia, there are benefits to them continuing to live in their own homes for as long as possible, both in improved quality of life and associated measures such as increased social contact, increased physical activity, lower use of medication, and reduced costs and burden of care. Tools to help extend the period of independent living, and to maintain quality of life in this period, are lacking. Systems exist to monitor individuals for problems, e.g. falls or wandering from the home, but there is scope for development of computerised support to help maintain activity in independent living. We aim to monitor achievement of activities, by app and by sensors, and provide recommendations on how to best maintain activities. We describe a goal model to monitor achievement and to suggest replacement activities and goals when an activity goal can no longer be achieved.**

Keywords- dementia; goal modelling; self-care; independent living.

I. INTRODUCTION

We report on our work on assisting Persons Living With Dementia (PLWDs) in living independently for as long as possible and with as much Quality of Life (QoL) as possible, work previously discussed in [1]. Dementia is a set of symptoms that may include deterioration in memory and the ability to focus attention; unpredictable behaviour; and decline in the ability to perform routine activities of everyday living. It can be caused by a number of conditions, with Alzheimer's disease being the most common cause of dementia in older people, contributing to 60-70% of cases [2]; other common causes of dementia are vascular dementia, Lewy Body dementia and fronto-temporal dementia [3]. Dementia symptoms are progressive and the disorder is incurable; Persons Living With Dementia (PLWDs) require increasing care as their underlying disease progresses. Different types of dementia progress in different ways and at different rates but overall the disease is one of irreversible decline. There is evidence to suggest activity-based therapies can slow this decline, for example physical exercise [4]. Currently, it is estimated that about 50 million people worldwide suffer from a form of dementia, with this number projected to rise to more than 131 million by 2050, reflecting aging populations around the world [5]. As well as the human cost of the disease, such as demands on family members acting as informal carers [6], there is a societal financial burden, estimated to be over $1 trillion a year worldwide, with 80-85% of these costs due to paid social care services and unpaid informal family care [7]. For people with early or moderate dementia, there are benefits to them exercising their personal preference of continuing to live in their own homes for as long as possible, both in improved QoL and associated measures such as increased social contact, increased physical activity and lower use of medication, and reduced costs of care [8]. Lower physical function is associated with increased risk of admission to long-term care, and so it is beneficial to maintain physical function for as long as possible [8]. It should be noted that only a minority of PLWDs living in their own home will move into a care home [9].

The Smart Dementia Care project [10] aims to develop a computerised toolkit to assist people with early-stage dementia to live independently in their own homes. This toolkit will support a PLWD and their informal family carer(s) in developing a personalised activity plan and will encourage each PLWD's compliance with their activity plan. The activity plan will incorporate goal targets derived from formal care plans, existing models of daily activities, and activities defined by the individual PLWDs and their carers as being activities that the PLWD finds rewarding and wishes to continue. The project is following a co-design methodology, where the research team includes PLWDs as experts in their condition and their lived experience of it. Achievement of goals by a PLWD will be measured by a combination of self- (or informal carer-) reporting via an app, and automatic data collection from body-worn or static sensors utilizing a variety of technologies, for example proximity sensors, humidity sensors, location sensors or motion sensors. The app and sensor data capture are under development in parallel with the work described in this paper. In this paper, we focus on the development of a computational goal framework to enable the specification of goals by PLWDs and the capture and quantification of their goal achievement data.

Persons with dementia should be at the centre of decision-making about their care and the regular activities that form part of their care [11] including basic activities (e.g., feeding themselves, dressing themselves), advanced activities (e.g., managing finances, using transportation), and activities meaningful to the individual PLWD (e.g., social and recreational pastimes). However, there is limited involvement of people living with dementia in the design of technology to support their care and their ability to live independently by helping them maintain the performance of activities required for the continuation of independent living.

According to a report investigating older people's preferences for care in Ireland, the majority of people with dementia would prefer to remain at home and in their community for as long as possible, utilising home-care support as an alternative to long-term residential care where possible and where feasible [12]. This is reflected in a report for the UK Alzheimer's Society [13] which states that 85% of people in the UK would prefer to remain living in their own homes following a dementia diagnosis [14; 13]. A central goal therefore is to enable people to remain in their homes for as long as possible while also providing care that is safe, timely, efficient, and as close to home as possible. As well as this, emphasis is placed on maximising the integration of natural supports such as family, friends, and social interaction.

The scope for assistive technology to play a role has been recognised as having the potential to improve QoL for both the person living with dementia and their informal carer(s), reduce carer stress, and foster and maintain a sense of independence and autonomy for the PLWD and those involved in providing care and support [15]. However, while there has been an increase in the development of technologies to support PLWDs, there remain gaps in healthcare technologies for self-management which provide support to PLWDs and their informal carers in their homes.

We describe the early development of a goal framework to enable personalisation of goals and tracking of goal achievement for persons with an early-stage dementing illness, with the aim of promoting independent living at home. Goals are developed from existing measures of human ability and disability, from activities defined in formal personal care plans, and activities that individuals desire to maintain as pleasurable or otherwise meaningful and so which enhance QoL. We present an initial outline of our framework, that includes the capture of information pertaining to each goal in each individual's personalised goal schedule, comparison of achievement with their personal target for included activities, and suggested actions to take in the case of under-achievement, whether that be persistent or short-term under-achievement.

The rest of this paper is organized as follows. Section II describes the process of selection of activities to be monitored. Section III describes the chosen activities and the selection of replacement activities. Section IV discusses possible burdens on PLWDs of this work. Section V gives conclusions, description of further developments of this work and an acknowledgement.

II. METHOD

A. *Activities and goals*

Goal-oriented Cognitive Rehabilitation (CR) is a form of therapy which aims to address and manage functional disability and maximise social participation and engagement using a person-centred, goal-oriented and problem-solving approach [16]. It uses evidence-based rehabilitative methods and involves PLWDs and their carers or family members working together with a therapist to identify meaningful and personally relevant goals related to everyday activities [17]. Strategies are collaboratively devised and implemented; evaluation in terms of progress towards goal attainment is based on both participant and informant-reported information [16; 18]. A multi-centre randomized controlled trial by Clare et al. [16] demonstrated that PLWDs were able to identify goals they felt were important and were motivated to address and attempt to attain and retain. In addition, results from their trial suggest that an individualised and goal-oriented implementation of CR can lead to improvements in everyday functioning, and it can be an effective intervention for people with early-stage dementia. One of the fundamental strengths identified from Clare et al.'s work was the possibility of transfer and generalisation, with the goals that were identified and being worked towards being relevant and applicable to improved functioning in real-world situations. Moreover, the suggestion was made by Clare et al. that, once delivered in a cost-effective manner, CR could be integrated into care pathways with a view to developing strategies for living with dementia in the community [16]. The Goal Attainment Scale (GAS) [33] has been used to measure achievement of goals in dementia. GAS itself is not specific for dementia and the particular goals used in any analysis for PLWDs are selected in cooperation with the PWLD. Table 1 shows an implementation of a GAS for the work described here, adapted from Turner-Stokes [20].

Phinney et al. [21] identified four categories of goal, based on interviews with and observations of PLWDs: (1) leisure and recreation; (2) household chores; (3) social involvements; (4) work-related goals. Interview participants stressed the importance of being able to continue engaging in these activities and the willingness to employ new strategies to do so should this be required as the disease progresses. Related to this is the importance of identifying those activities that were valued and enjoyed before the onset of dementia since these are likely to be considered intrinsically meaningful in terms of everyday life and past experience [21].

We wish to encourage PLWDs to achieve goals in activities that will help maintain their ability to live independently in their own homes for as long as possible and which will give them the greatest QoL as possible.

In particular, we wish to encourage PLWDs to perform activities that fall into one of three groups:

TABLE 1. GOAL TARGETS AND THEIR MEASUREMENT

Activity source:	**(I)ADL/ MWDS**	**Care plan**	**PLWD/ Carer**
Specific activity:	Preparing a meal	Walking outside	Visiting a friend
Optionality:	Core	Core	Optional
Frequency goal:	Once a day	Once a day	Once a week
Duration goal:	20 minutes	60 minutes	120 minutes
Duration data source:	Sensors/ Self-report	Sensor	Self-report
Achievement goal:	Successful preparation	Walk 2.5 km	Visit friend
Average frequency:	5/week	6/week	0.8/week
Average duration:	24 minutes	55 minutes	140 minutes

(i) Basic Activities of Daily Living (ADLs) and Instrumental Activities of Daily Living (IADLs). These activities are the most basic activities that together allow individuals some degree of independence. ADLs are the ability to bathe oneself, select clothes and dress oneself in the correct sequence, toileting, transfer, continence, and feeding, activities defined by Katz et al. in 1963 [22] and now well-established. IADLs are the more sophisticated instrumental activities of making a telephone call, shopping, meal preparation, using transportation, doing laundry, and financial management, activities defined by Lawton and Brody in 1969 [23] as being those that enable independent living and are similarly now well-established. Each of these scales measure the ability of individuals to perform basic activities of daily living and activities required for independent living. These scales were created to allow scoring of the degree of self-maintenance functions that individuals are able to perform for themselves, with the Katz scale measuring more basic functions than the Lawton-Brody scale. It is important for these activities to be maintained for as long as possible both for those with dementia and those without dementia, but for those with some forms of dementia (including Alzheimer's, the most common form), once the ability to perform an activity is lost, it cannot be regained. Retaining the ability to perform ADLs will benefit PLWDs even after they can no longer live independently. In Ireland, where this work is being performed, the Modified Winchester Disability Scale (MWDS) [24] dominates assessment of risk in older adults. Additional to the ADL and IADL scales it includes measures of mental and social activity. It should be noted that none of these scales are specific for PLWDs.

(ii) Activities defined in individuals' formal care plans. Care plans are agreed between health and care professionals, the PLWD and their family carers. They are documents that record the care needs of a PLWD and their informal carers. Formal Care Plans contain a variety of information useful to the PLWD and their family carers, and are usually drawn up in cooperation with health professionals (see, for example, the discussion on care plans in Burt et al. [25]). They can include such useful and essential information as medication and prescriptions details, emergency telephone numbers, allergies, etc. They can also include a set of activities that are essential and/or enjoyable to the PLWD, such as personal hygiene; going for a walk; preparing lunch; gardening. The plan can include goals which may be related to performing specific activities. Examples of the possible content of a care plan can be found in [26]. These care plans are relatively static, often paper-based and reviewed only annually, not computerised or interactive, and so the degree of responsive personalisation for each PLWD is limited. Should such activities be present in a care plan they can be included in the toolkit.

(iii) Meaningful activities (MAs): Meaningful activity can be described as any activity that results in emotional, creative and intellectual stimulation, while also providing increased levels of wellbeing and QoL over the course of an adult's life [27]. Engagement in meaningful activity has been found to positively affect overall health and wellbeing in a number of ways, including increased positive emotions, improvements in ADL performance, improved overall QoL and well-being, positive relationships with carers, and reduced behavioural symptoms [28]. Activities comprise a broad range of tasks and endeavours, ranging from household chore to recreation and social involvement. In essence, they are activities that bring pleasure or satisfaction (i.e. they have meaning) to PLWDs.

Example sets of such MAs exist, e.g. Mahoney and Barthel [29], but it is unlikely that any one PLWD will wish to enjoy all activities in any one defined set, and they may have wishes to enjoy activities that are not in any existing sets of pleasurable activities. In proposing and selecting the use of MAs as a therapeutic tool, we take inspiration from work from such organisations as the NHS [30]. The set of activities in this group will be tailored to each PLWD and are chosen because they bring pleasure to that person and/or have other benefits, such as the health benefits gained from, for example, an enjoyable walk, that can help maintain QoL.

Each PLWD, or their carer, will be asked to describe activities such as socialising, hobbies or exercising that the PLWD enjoys and wishes to maintain. From this list of activities, a set of activity goals will be agreed with the PLWD and included in that individual's set of goals to be achieved. Additionally, a prepared set of activities, derived from our literature review and from co-design sessions attended by PLWD and their carers, will be presented to PLWDs and their carers as prompts to ensure that they have not omitted any activities that they do enjoy but may not recall unprompted in interview. Two scales that measure pleasurable events or emotions in dementia were found: Teri and Logsdon's PES-AD [31], a set of activities and events created to measure the QoL of individuals with Alzheimer's Disease, and Smith et al.'s DEMQOL [32]. These scales focus on QoL rather than basic activity achievement. Smith et al. focused on recording changes in emotional states, whereas Teri & Logsdon focused on the accomplishment of actual events. Our initial list is based on the PES-AD scale. Example PES-AD activities include: Having friends visit; doing jigsaw puzzles; gardening; going to church. Each MA has associated with it a number of attributes that are required to perform that activity, which may be ADLs, IADLs, exercise specific functions, or bring other benefits.

B. *Activity selection*

In order to realise our aims of extending the period spent in independent living for PLWDs as much as possible, the expectation to exercise ADLs and IADLs will be standard for all PLWDs, with the caveat that new activities should not be introduced for PLWDs who had not previously routinely performed that activity (shopping, or preparing meals, for example). Performance of ADLs and IADLs will be regularly monitored. Other activities – the MAs - will be personalised using the formal care plans and wishes of each individual PLWD. Monitoring changes in goal achievement over time allows for a greater degree of personalisation for each PLWD. We reviewed the literature relating to basic activities of daily living, including scales used in determining the abilities and disabilities of PLWD and any goals for these basic activities. Similarly for pleasurable activities we reviewed the literature relating to measuring the frequency and degree of such activities and of related emotions.

MAs have associated with them a number of attributes. As well as the ADLs and IADLs that may be exercised during the achievement of a MA, there are also benefits from exercising cognitive functions, and the benefits of improved QoL. The American Psychiatric Association [33] defines the cognitive functions as Learning and memory; Language; Executive function; Complex attention; Perceptual-motor; Social cognition. Tuijt et al. [34] identified six domains of meaningful or enjoyable activities into which activities could be categorized: physical activity; looking after my household; enjoyable and leisure activities; hobbies and personal interests; staying mentally active; and social activities/community involvement. Should a PLWD no longer be able to perform a MA, they may lose the QoL benefit of performing the activity and may also lose the more basic benefits of performing the ADLs and the IADLs, and of exercising the cognitive functions that may have been exercised by that activity. In order to maintain the benefits of the lost activity, it is proposed to suggest to PLWDs possible replacement MAs. Replacement MAs will be selected and ordered using, in the first iteration, a simple machine learning method, ‘k nearest neighbours’ [35]. This method uses attributes of an entity to identify closely matching entities from a set (in this case, using the IADLs, cognitive functions and domains fulfilled by exercising the ‘lost’ MA to identify MAs in the master set that most closely match the attributes of the ‘lost’ MA).

ADL, IADL and PES-AD activity sets were each drawn up several decades ago and some activities included could benefit from updating. For example ‘making a telephone call’ should now allow for communication using SMS, email, or social media, as well as voice calls, using landline telephones, mobile telephones, tablets or laptop computers. Other activities may need to take into account restrictions due to the current COVID-19 pandemic, e.g., 'going to church' may need to also allow for 'attending church services remotely'. Additional activities will be identified through co-design workshops attended by PLWDs and their family carers. To achieve this, Lindsay et al. [36] suggest including carers in meetings to provide support during discussions where communication issue arise while also paying close attention to instances where the carer may speak on the care recipient’s behalf. It has also been pointed out that operating separate interviews and workshops for people living with dementia and for carers can allow participants to express themselves freely without either being spoken over (in the case of the person living with dementia) or feeling reluctant to discuss negative aspects of the caring process (in the case of carers) [37, 38]. At the same time, it is important to consider that carers and family members may eventually become the primary user and facilitator of these technologies due to declining abilities and the progression of the disease.

Goals will be determined for each PLWD for each of the established ADLs and IADLs, and to measure each PLWD’s achievement in reaching these goals. Further, for each PLWD, we take individualised goals from their formal care plans and from their chosen MAs, again measuring their achievement of these goals. Measurement of these goals will be either by PLWD or their family carer entering information directly into the toolkit interface, or by automated data collection by sensors where this is feasible.

For each activity included, for example ‘ability to shop for oneself’ or ‘going to church’, a decision needs to be made on the appropriate metric to determine achievement of each goal, and how to measure achievement of the goal . We aim to establish baseline target goal levels based on the PLWD’s existing performance in order to maintain performance of activities and improve wellbeing.

Existing scales of daily activities and pleasurable activities can be utilised to create a set of goals for individuals with dementia. Performance of these goals by PLWDs can benefit their QoL and help them maintain their ability to live independently. Achievement of these goals can be directly reported by PLWDs or their family carers via a computerised toolkit’s interface, or can be determined by data collected by sensors. Information recorded for each activity will include quantifiable information such as start time, end time, duration, achievement, comparison with goal target, and a measure of pleasure or satisfaction. For example, a PLWD may have had a daily walk starting at 10am and finishing at 10:45am, lasting 45 minutes, walking for 2.5 km and exceeding a target of 2 km. This activity exercises some cognitive functions (Executive function; Complex attention; Perceptual-motor) and has QoL benefits from the ‘enjoyable and leisure activities’ domain. The measurable achievement score – in this case 45 minutes, 2 km – can be tracked over time, providing information to the PLWD and their carers about which areas of their daily life may require attention, potentially in the form of advice in improving achievement.

III. RESULTS

Examples of some typical goals are shown in Table 2. Included in the table is information on each goal, illustrating how we intend to quantify the achievement of each goal. ADLs are not included in the set of explicitly monitored activities since they are measured on a binary achievement scale which will be achieved by all PLWDs in the early stages of dementia, and which do not in themselves allow PLWDs to maintain independent living. Where possible, it is intended to monitor the performance of ADLs by use of sensors to capture information regarding achievement of ADLs, for example the time taken to get dressed, to monitor any gradual decline in performance of achieved ADLs.

Each example in Table 2 shows a different type of goal. ‘Preparing a meal’, an IADL, is a basic activity we wish to encourage the PLWD to maintain as essential for continued independent living. ‘Walking’ is often included in care plans for the health benefits it brings. ‘Visiting a friend’ is a little different from the previous two activities, as it is included as being chosen by the PLWD as a pleasurable activity that helps maintain their QoL. Each activity has several dimensions that can be quantified: duration of activity, frequency of activity, activity achievement (e.g., distance walked, completeness of meal preparation). Measurement of these dimensions can be recorded by sensors, by asking the PLWD or their family carer to enter information on goal achievement into an app, or by a combination of the two. Using this approach allows for finer granularity of information to be captured contemporaneously rather than the usually retrospective information capture necessitated when information is gathered by visiting healthcare professionals.

Activity information is collected daily from the app and from sensors, and added to the historical data. Information relating to that day’s activities is then analysed. In particular, that day’s activities performance is compared to the targets for each activity. For those activities where the target is met, the target is met, an appropriate encouraging confirmatory message is sent to the PLWD. Background analysis of the performance of the activity over time is also performed to see if there is a measurable decline or improvement in activity performance, irrespective of whether the target has been achieved. For activities which are not achieved, the initial action is to send a message to the PLWD to either remind them to perform the activity or to encourage them to improve their performance. If it becomes apparent that a MA is no longer being achieved with any regularity, then a replacement MA (or set of replacement MAs) is chosen for recommendation to the PLWD. Determination of replacement MAs is based on the continuation of achievement of the attributes intrinsic to the achievement of the ‘lost’ MA. These attributes may be IADLs, skills and/or themes.

TABLE 2. GOAL TARGETS AND THEIR MEASUREMENT

Activity source:	**(I)ADL/ MWDS**	**Care plan**	**PLWD/ Carer**
Specific activity:	Preparing a meal	Walking outside	Visiting a friend
Optionality:	Core	Core	Optional
Frequency goal:	Once a day	Once a day	Once a week
Duration goal:	20 minutes	60 minutes	120 minutes
Duration data source:	Sensors/ Self-report	Sensor	Self-report
Achievement goal:	Successful preparation	Walk 2.5 km	Visit friend
Average frequency:	5/week	6/week	0.8/week
Average duration:	24 minutes	55 minutes	140 minutes

Table 3 shows an example of a MA that might be chosen by a PLWD as an activity that had meaning to them and that they enjoyed on a regular basis, and includes a small subset of other MAs for comparison. For the purposes of the examples, it has been assumed that the preferred MA, ‘coffee with friends’, involves travelling to a coffee shop, purchasing items in the shop, and socializing with friends. Thus the ‘travelling’ IADL is being exercised, the ‘perceptual-motor’, ‘complex attention’, ‘language’ and ‘social cognition’ skills are being exercised, and meaning is achieved in the ‘enjoyable/leisure’ and ‘social/community’ domains. When this MA, ‘coffee with friends’, is no longer being achieved on a regular basis, the achievement of the particular IADLs, the exercising of particular cognitive functions and the pleasure gained from particular domains may be lost. The table includes indication of which IADLs, cognitive functions and domains are fulfilled when the MA is achieved. If this MA is no longer being achieved then alternative activities that exercise the IADLs, cognitive functions and domains should be adopted. Suggestions are made to the PLWD (or their informal carer) of possible alternative activities (or sets of activities) that can exercise the IADLs, cognitive functions and domains that are not exercised if an MA is no longer achieved. Potential replacement activities are selected from the existing set of MAs according to how well the potential replacement MA matches.

To select candidate MAs for suggestion to a PLWD as potential replacements for a lost MA, the full set of MAs is examined to find those MAs that most closely match the MA that is no longer being performed. Note that Table 3 shows only a small subset of the set of MAs maintained for this study, for illustrative purposes. The full set of MAs is based on the work of Teri and Logsdon [31] with additions from PLWDS in this study who suggest MAs that are meaningful to them. The closeness of matching of candidate replacement MAs to the lost MA is calculated using a simple k nearest neighbours method, chosen for its simplicity and explainability. For the knn distance between activities, the simplest calculation method is employed, that of the number

TABLE 3. SOME MEANINGFUL ACTIVITIES AND THE ATTRIBUTES THEY EXERCISE

Activity type	Attribute / MA:	Coffee with friends	Being outside	Video meeting with friends	Gardenig outdoors	Having friends visit for lunch
IADL	Telephone			Y		
	Shopping	Y				
	Food	Y				Y
	Laundry					
	Transportation	Y				
	Finances					
Cognitive function	Learning and memory				Y	
	Language	Y		Y		Y
	Executive function	Y		Y		Y
	Complex attention	Y		Y		Y
	Perceptual-motor	Y			Y	Y
	Cognition	Y	Y	Y	Y	Y
Domain	Enjoyable/leisure	Y	Y		Y	
	Look after house					
	Hobbies/interests				Y	
	Mentally active	Y				Y
	Social/community	Y		Y		Y
	Distance (knn)	-	2	5	3	8

of attributes that match. This knn distance calculation is included in Table 3 as 'Distance (knn)'.

Results from this calculation allow the candidate MAs to be ordered by their closeness to the lost MA by using the Distance (knn) result: Having friends visit for lunch (8, closest match); video meeting with friends (5); gardening outdoors (3); being outside (2, most distant match).

The most closely matching MAs are presented to the PLWD as candidate replacement activities. Once the PLWD selects a replacement MA, the attributes of this MA are compared with the original lost MA to determine if any attributes remain unfulfilled. Assuming that the PLWD selects the most closely matching candidate MA from the example set in Table 3, 'Having friends visit for lunch', does not necessarily fulfil the shopping IADL (although it may do and this can be established), the use of transportation, and may not qualify as an activity in the enjoyable/leisure domain. It should be ensured that these specific activities continue, either by the addition of a second new MA (in the set in Table 3 for example, 'being outside' can fulfil the 'enjoyable/leisure' domain) or setting goals to exercise specific IADLs (in the example set in Table 3, use of transportation may need to be explicitly exercised). Figure 1 shows the complete workflow to be implemented.

IV. DISCUSSION

In order to record achievement of activities, data on achievement of activities must be captured. This can be done by using sensors, with little or no demand on the PLWD, or by active self-reporting of activity data by the PLWD or their informal carer. We believe that of the 12 ADL and IADL activities, seven can be monitored by use of sensors, e.g. the 'bathing' ADL can be detected by use of capacitive humidity sensors and resistance temperature sensors in the bathroom and analysing the output from the sensors to detect use of the bathroom. We are developing techniques for performing this event detection, leaving five activities that will require self-reporting (i.e. manual entry of data into the app) of achievement of activities by the PLWD (e.g. completion of a 'shopping' activity). Table 4 summarises which ADLs and IADLs can be monitored by use of sensors and which require to be self-reported. The intention of the co-design methodology is that, by engaging with PLWDs at the app design stage, the app will be simple to use and be seen by the PLWD as a device of empowerment rather than a burden. By including activity reminders and goal targets it is intended that the app be a useful assistive tool, and our early feedback from carers is that this will be so. However, we await the outcome of the full co-design sessions and feedback on use of the developed app to confirm or otherwise that this is the case.

In order to design useful and usable technologies that will be used by PLWDs to support and maintain independence, it is necessary to understand their point of view and lived experience, without focusing solely on impairments commonly associated with dementia [36]. It is also important to note that personal, social, and environmental factors as well as a PLWD's specific disabilities result in needs, wishes and abilities which can vary significantly [39]. Involving end

TABLE 4. MONITORING METHODS FOR ADLS AND IADLS

Activity group	Activity	Monitoring method
ADL	Bathing	Sensors
	Dressing	Sensors
	Toileting	Sensors
	Transferring	Self-reporting
	Continence	Self-reporting
	Feeding	Sensors
IADL	Telephone	Sensors
	Shopping	Self-reporting
	Food	Sensors
	Laundry	Sensors
	Transportation	Self-reporting
	Finances	Self-reporting

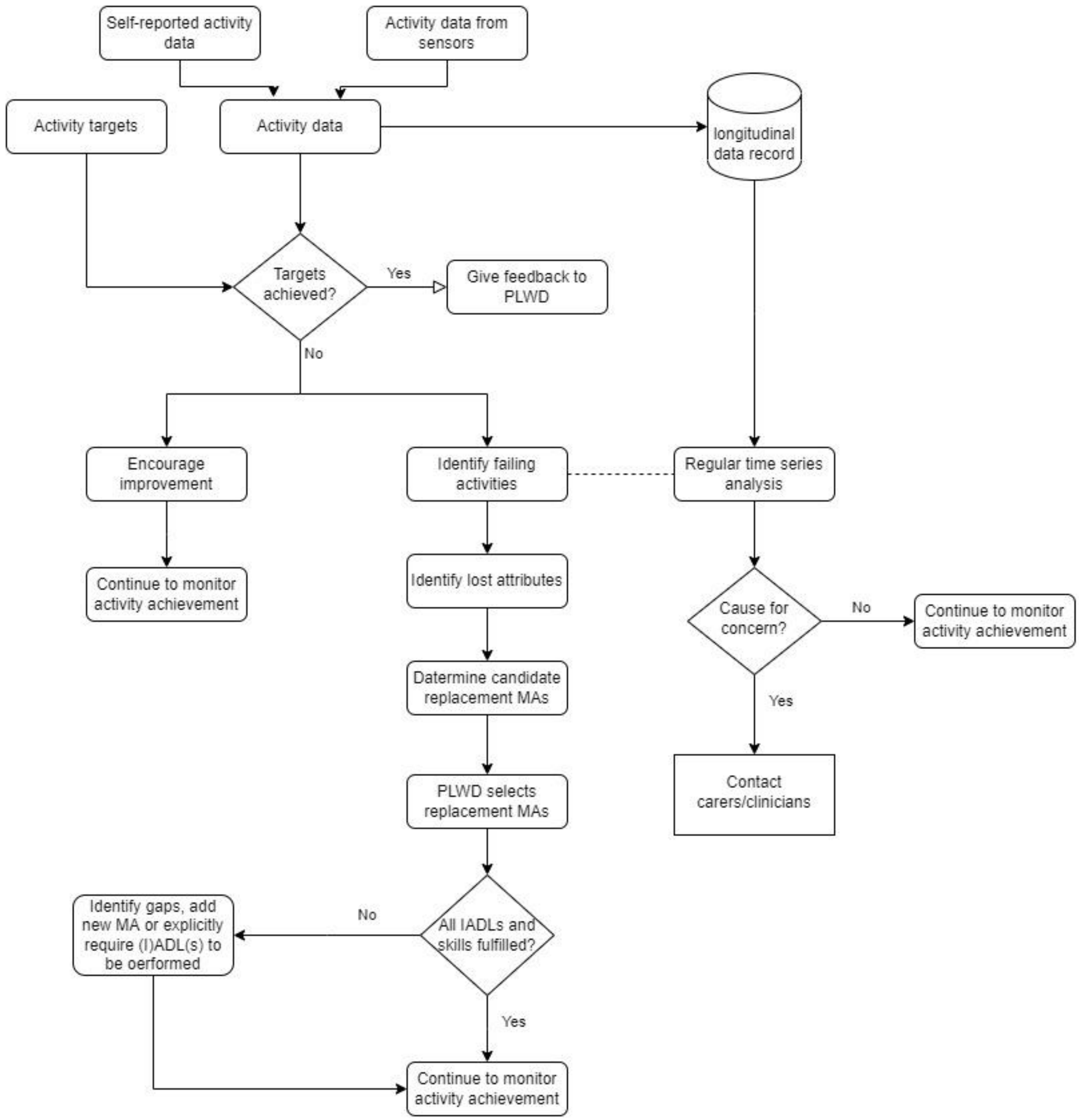

Figure 1. Workflow to capture activity data and suggest alternative activities

users considers the likely gulf between the day-to-day lives and life experiences of designers or researchers and PLWDs. Moreover, involving PLWDs in the design process can improve usefulness and acceptability of assistive technologies while also resulting in feelings of empowerment [40]. Being given a voice in this manner has led to designs that improve social interaction [41] and help to maintain independence through support for ADLs [42].

Mobile technologies and applications that allow for customisation can adapt and respond to the needs of individual users, which is considered particularly important for the developing needs of PLWDs in terms of cognitive deterioration and gradual decline in abilities [43; 44]. Among the themes to emerge from work carried out by Lindsay et al. [36] was the importance of a design feeling personal to the individual PLWD (due to the degree to which individual circumstances vary), while also integrating into the person's routine. Such factors were deemed crucial to determining whether a new device would be accepted. This can be achieved by taking an approach that focusses on a personally tailored design that considers an individual's day-to-to experiences, and the way routine is used to cope with daily challenges. Adopting this design approach, developing a relationship between the designer and the participant, and creating individually tailored prototypes thereby allows for a scenario where participants can focus on individual problems and get a feel for what a design that works for them specifically may look and feel like [40].

There is some literature on behaviour change, such as the work of Fogg et al. [45], Oinas-Kukkonon [46], Reimer et al. [47] and Webb et al. [48], which will inform our work on assisting PLWDs to continue to maintain good behaviours. In particular, Fogg et al.'s categorisation of new behaviours into 'one-time', 'temporary' or 'permanent'. We take further inspiration from the transtheoretical model of health behavior change of Prochaska and Velicer [49], in particular because we are aiming at maintaining activities of PLWDs rather than changing them.

The success of our system will be measured by recording the period of independent living of our participant PLWDs against current established times for independent living following diagnosis with a dementing illness, the rate of decline in performing activities, and the adherence to self-reporting of activity performance. Limitations on our work are the engagement of PLWDs and their carers, the technology challenges of tracking activities by sensors, and the appropriate selection of activities and activity achievements.

V. CONCLUSIONS

A set of goals for PLWDs can be constructed from existing scales of performance and disability, including scales that are not specific for dementia, those that are specific, and from care plans. Additional goals can be included following discussion at co-design workshops and interviews with individual PLWDs. Goal targets can be determined from care plans, from existing achievement levels of PLWD and their activity achievement ambitions. In this work we are focusing on the using the standard ADLs [22] and IADLs [23], activities recommended by clinicians derived from formal care plans, and MAs selected by the PLWDs. The set of goals and goal targets can be used to construct a framework that will allow for computational models to determine goal achievement and suggestions to maintain or achieve goal targets.

Goals and goal achievements are formally specified in conjunction with PLWDs. The set of IADLs is taken from Lawton-Brody [23], with achievement goals set in collaboration with PLWDs. Activities and goals from formal care plans are those specified for each individual PLWD. The MAs and goal targets are those specified by individual PLWDs. When performance of an MA has declined such that it is no longer being performed, replacement MAs are suggested using a simple knn approach that aims to ensure that the benefits of performing the lost MA are maintained, in particular the cognitive functions, the domains of pleasure or meaning, and the exercising of the IADLs.

Future work will include developing methods of capturing goal achievement information with minimum burden to the PLWD, by using an app with a simple interface and/or capturing and processing data automatically from sensors; developing appropriate methods of prompting or encouraging PLWDs to achieve or repeat goals, and mapping relationships and dependencies between goals (for example, the ability to walk or drive a minimum distance, or the ability to use public transport, which may be necessary for the ability to perform independent shopping). A pilot implementation of the system in the homes of 6 PLWDs is planned, to include evaluation of activity achievement, and burden of activity tracking on the PLWDs and their carers.

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The Stakeholders' Views on the Growth of Telemedicine Use

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***Abstract*— The views and experiences of the stakeholders on the use of telemedicine play an important role in the development of the service. This study aims to investigate the willingness of Japanese people to use the telemedicine service, and identify cases/situations it is preferred to use for. It also identifies the stakeholders' opinions and needs to increase actual use of telemedicine. To achieve our goals, two different types of stakeholders were selected, including general public and medical doctors. Regarding the first group that includes ordinary people, 84 participants in the age ranging from 20 to 64 years were randomly selected, and data were collected from them using a questionnaire. As for the second group of participants, online interviews were conducted with 25 physicians (with ages ranging from 30 to 65 year) working in different scopes of medicine. The results of both surveys reveal that all participants except three doctors had never experienced telemedicine despite COVID-19 state of emergency. Less than half of the participants in each group expressed their willingness to use telemedicine at present. Furthermore, the majority of our participants pointed out that telemedicine is a good tool for virtual visits to inpatients by their loved ones. Based on the stakeholders' views and needs, this study identifies two approaches to increase telemedicine utilization. First approach aims to expand the scope of telemedicine, so that encompasses various issues, which currently concern the community in Japan. The second one focuses on improving the telemedicine platform through different actions recommended by each group of participants.**

Keywords* - *Telemedicine; Service Development; Stakeholders, Views and Needs

I. INTRODUCTION

Since 2018, telemedicine has been covered by Japanese insurance, but the incentive to promote telemedicine is weaker than that of other countries partially due to free access to medical institutions and other issues [1] [2].

Telemedicine can be defined as the use of electronic communications and information technologies to provide clinical services when participants are at different locations [3]. In April 2020, the COVID-19 crisis has prompted Japan to ease regulations on telemedicine [4]. However, the use of deregulated telemedicine has been sluggish compared to the US and UK. In Japan, only 15% of medical institutions have deployed telephone or online consultations [5]. Therefore, this study investigates public willingness to use current telemedicine service. It also identifies the needs of different stakeholders to develop telemedicine. In this study, the use of diverse population samples is useful to create an inclusive telemedicine service that meets the needs of as many people as possible. We focus on two types of stakeholders, including general public and medical doctors.

The rest of this paper is organized as follows. Section II explains the method of this study. Section III shows the results of the survey. Section IV includes discussion and limitation of a study. Section V includes conclusion.

II. METHOD

To achieve our goals, online 'semi-structured' interviews 'including 20 questions' were conducted with 25 Japanese physicians (21 males and 4 females) between August and October 2020. The doctors were randomly selected for this study. Furthermore, a semi-structured questionnaire (9 multiple-choice questions) was undertaken with 84 individuals from the public (63 females and 21 males) between February and April 2021. Selecting the questionnaire participants was based on their busy works with limited vacations time (about 10 days in a year) to visit hospitals. The questionnaire sheets had been given to the person in charge of the department by hand in order to distribute it to all the employees. Based on the literature review [6] [7], the questionnaire was designed, and then piloted on 5 individuals. From the responses of 5 people, the questions were revised and determined. Probing questions were used to determine the best patterns and circumstances for making telemedicine services more usable and efficient.

In this study, all participants were provided with an explanation of telemedicine and all information regarding the study, including the purposes for undertaking the surveys. Ethical approval for this study was obtained from the Kyushu University Hospital, permission no. 2021-15.

III. RESULT

The questions were answered by two various types of stakeholders. First group includes 84 administrative employees (63 females and 21 males). Second group includes 25 medical doctors (21 males and 4 females). The following are the main results of the surveys.

A. *The Characteristic of Participants*

The first group includes the general public, and with ages ranging from 20 to 64 years.

TABLE I. CHARACTERISTICS OF PARTICIPANTS IN THE FIRST GROUP (N=84)

Gender N=84	Age	N=84	Physical Disability	City	Occupation Administrative Employee	N=84	Hospital Visit	in a year	N=84	Awareness of Telemedicine	Experience of Telemedicine
Female	20-29	17 (20%)	No	Fukuoka	University A	N 53 (63%)	Once a week	52 times	2 (2%)	Very much	No
N 63 (75%)	30-39	16 (19%)			University B	N 31 (37%)	Once every 2 weeks	26 times	2 (3%)	N 14 (17%)	
	40-49	28 (34%)					Once a month	12 times	16 (19%)	Somewhat	
	50-59	17 (20%)					Once every 2 months	6 times	6 (7%)	N 59 (70%)	
Male	60-69	6 (7%)					Once every 6 months	2 times	24 (29%)	Not at all	
N 21 (25%)							Once a year	One time	12 (14%)	N 11 (13%)	
							No visit	0	0		
							No answer	—	22 (26%)		
100%	100%	100%				100%			100%	100%	

TABLE 2. CHARACTERISTICS OF PARTICIPANTS IN THE SECOND GROUP (N=25)

Age of Participants		Gender		Affiliation	
30-39 years	11 (44%)	Male	21 (84%)	University hospital	14 (56%)
40-49 years	8 (32%)	Female	4 (16%)	Non- university hospital	2 (8%)
50-59 years	5 (20%)			Clinic	9 (36%)
60-69 years	1 (4%)				

Participant	Gender	Years of work	Affiliation	City	Scope of practice	Awareness of telemedicine	Experience of telemedicine
1	Male	11	Hospital 1	Fukuoka	Gastroenterology	Very much	No
2	Male	11	Hospital 1	Fukuoka	Gastroenterology	n=5 (20%)	No
3	Male	10	Clinic 1	Saga	Otorhinolaryngology	Somewhat	No
4	Female	9	Hospital 2	Kitakyushu	Collagen Disease	n=18 (72%)	No
5	Male	20	Hospital 1	Fukuoka	Otorhinolaryngology	Not at all	Yes (3 months)
6	Male	7	Hospital 1	Fukuoka	Otorhinolaryngology	n=2 (8%)	No
7	Male	6	Hospital 3	Nogata	Otorhinolaryngology		No
8	Female	18	Hospital 1	Fukuoka	Dermatology		No
9	Female	6	Hospital 1	Fukuoka	Dermatology		No
10	Male	20	Hospital 1	Fukuoka	Dermatology		No
11	Male	6	Hospital 1	Fukuoka	Dermatology		No
12	Male	14	Hospital 1	Fukuoka	Dermatology		No
13	Male	18	Hospital 1	Fukuoka	Neurology		Yes (3 months)
14	Female	17	Clinic 2	Fukuoka	Gastroenterology		No
15	Male	17	Clinic 2	Fukuoka	Gastroenterology		No
16	Male	16	Clinic 2	Fukuoka	Gastroenterology		No
17	Male	34	Hospital 1	Fukuoka	Diabetology		Yes (3 months)
18	Male	28	Clinic 3	Fukuoka	Gastroenterology		No
19	Male	20	Clinic 4	Fukuoka	Gastroenterology		No
20	Male	24	Hospital 1	Fukuoka	Gastroenterology		No
21	Male	25	Clinic 5	Fukuoka	Otorhinolaryngology		No
22	Male	40	Clinic 6	Fukuoka	Orthopedics		No
23	Male	25	Clinic 7	Fukuoka	Ophthalmology		No
24	Male	6	Hospital 1	Fukuoka	Gastroenterology		No
25	Male	10	Hospital 1	Fukuoka	Gastroenterology		No

They are administrative employees working (full-time job) in different business sectors at 2 public universities in the Fukuoka city. The results of the questionnaire indicated that all participants have no physical disabilities, and are not telemedicine users. Fifty-nine (70%) of them are somewhat aware of telemedicine. The majority (29%) visit the hospitals about 2 times a year (Table 1).

On the other hand, the second group includes medical doctors with ages ranging from 30 to 65 years old. They are working in various scopes of medicine (including internal medicine, neurology, dermatology, orthopedics, otorhinolaryngology and ophthalmology), and at different healthcare facilities (including university and non-university hospitals as well as small clinics). The results of online interviews with 25 physicians revealed that at the beginning of COVID-19 pandemic (from May to August 2020) only 3 out of 25 doctors practiced telemedicine (hospital-based telemedicine) via telephone (audio only visit). Furthermore, we found that 18 (72%) of them were somewhat aware of telemedicine (Table 2).

B. *Opinions Towards the Use of Telemedicine Service*

All participants were asked about their interest in and willingness to use telemedicine. Regarding the first group (see Figure 1), less than half (46%) of participants answered with “yes”. About 37 (44%) of participants chose “I’m not sure”, and 8 (10%) of them responded with “no”. Concerning the situations/cases, in which the participants may use a telemedicine for, 65 (77%) of them would prefer to use the service in the state of a personal emergency “mild illness”, while 30 (36%) participants might use the service when it is imposed by policies or other means. Twenty-five (30%) participants answered that when a hospital is far from home, while 15 (18%) participants responded that it might happen for prescription renewals and chronic care management. A few (7%) participants indicated that in all cases, they will not use telemedicine, and 3 (4%) participants chose “other”.

On the other side, the majority (48%) of doctors in the second group expressed their interest in telemedicine despite its shortcomings which have a negative effect on the use of a service (see Figure 2). Regarding the major reasons for abandoning a telemedicine at present; 15 (60%) doctors stated their inability to perform an accurate and complete physical exam for the patients, while 12 (48%) of them mentioned lower revenues of telemedicine. Furthermore, 7 (28%) doctors stated their preferences for in-person visit over a telemedicine (such as; P # 2 stated that “*it is not possible to build trust with the patients through telemedicine*”, and P # 8 mentioned that “*the relationship between doctor and patient is based on trust. This trust strengthens when people actually meet each other. In virtual consultation, even trust becomes virtua*l”). About 6 (24%) participants stated the barriers related to telemedicine work environment (including regulations and facilities). Further, 6 (24%) doctors indicated social influences on their decision-making, while 3 (12%) doctors stated other issues, such as most of the patients are elderly and have poor ICT skills (see Figure 3).

C. *Expanding the Scope of Telemedicine*

The participants were asked about their issues/concerns, which could be well addressed through online care services. The majority (62%) of participants in the first group indicated that telemedicine is a good tool for virtual visits to inpatients by their loved ones and/or conducting remote follow-up meetings with the family members who are unable to be with their hospitalized patients. Forty-two (50%) participants stated that telemedicine could be effectively used for following up care, including post-operative follow up, while 39 (46%) participants mentioned that the service is a suitable way to educate people about lifestyle diseases. Twenty - two (26%) participants indicated that telemedicine can be used for patients on board (such as emergency medical care on the express train or at the sea by providing medical advice for the passengers on board ships), while 19 (23%) participants stated their needs to school-based telemedicine program for providing access to high-quality healthcare in the school setting. A few (12%) participants mentioned the need to use telemedicine for birth control counselling. Eight (10%) participants chose “other” (see Figure 4). On the other hand, the result of online interviews detected that the majority (40%) of physicians agreed with the first group of participants on the suitability of telemedicine for the virtual visits to inpatients by their loved ones and relatives.

D. *Actions to Improve a Telemedicine Platform*

We asked the participants about their views and needs to improve a telemedicine platform. The majority (49%) of first group indicated the importance of creating a user-friendly telemedicine program (see Figure 5). Twenty-four (29%) participants suggested to provide telemedicine in higher number of hospitals and be for all, while 21 (25%) participants requested to make the service available at any time “24 hours a day, and 7 days a week”. Twenty (24%) participants indicated the necessity to offer many value-added programs to telemedicine patients as a part of their wellness programs, while 18 (21%) participants requested to make the services easy to access without having Internet connection problems. About 17 (20%) participants responded that telemedicine must consider desires and needs by age demographic. Ten participants (12%) chose “other”, such as recommended that telemedicine be held to the same standards of in-person care, and establish unique patient engagement strategy that focuses on creating greater awareness of telemedicine’s potential and its usage.

Regarding the doctors' viewpoints and needs, the following are the most important actions to develop and expand the telemedicine service.

- Recommendations for telemedicine expansion:

P # 2 *“Due to some issues, telemedicine will not spread in Japan unless it is mandated by policy or other means”.*

P # 3 *“Patients are not ready for telemedicine. They should learn about the service as a quick option to receive care”.*

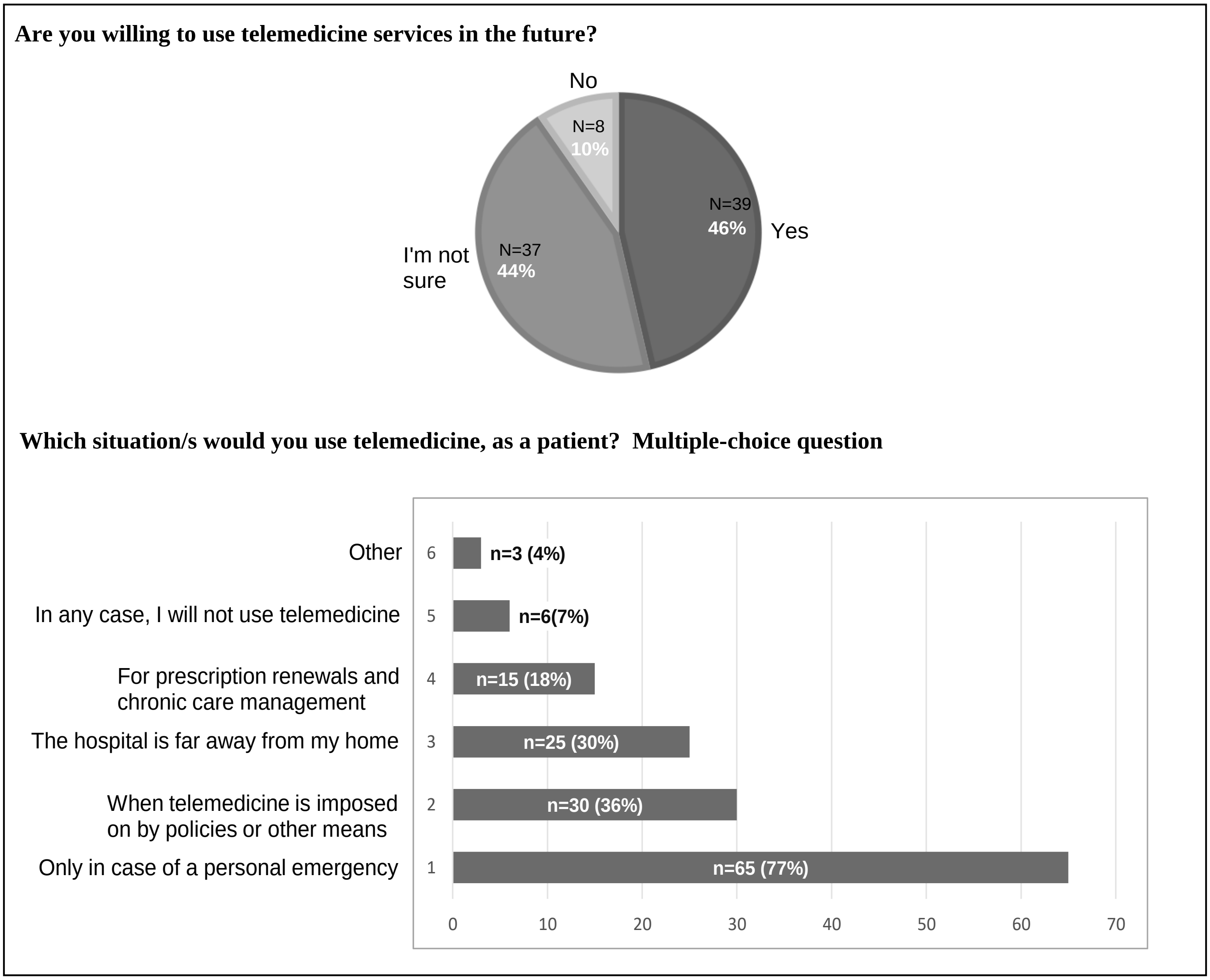

Figure 1. Telemedicine utilization in Japan (ordinary people, N=84)

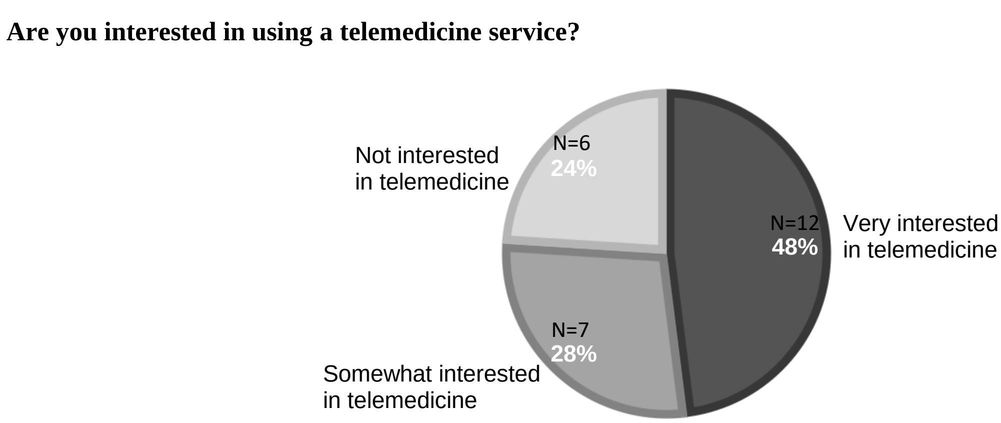

Figure 2. Physicians interest in Telemedicine (N=25)

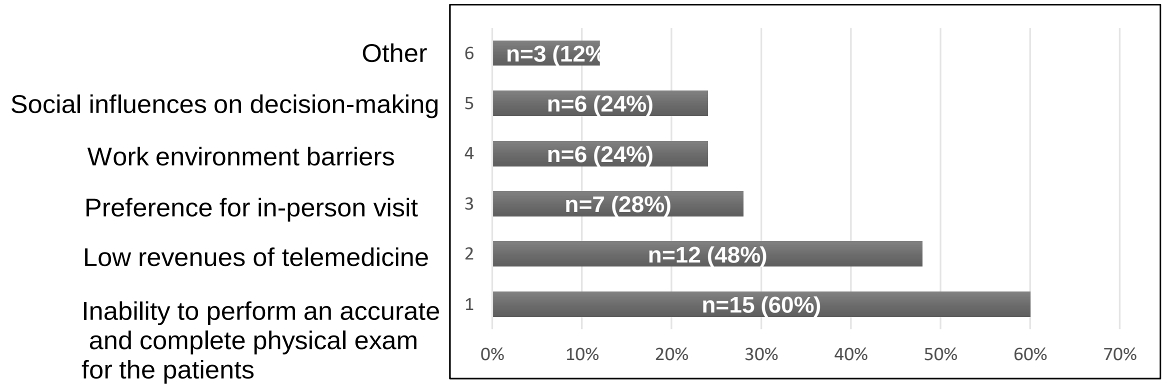

Figure 3. Major reasons for abandoning a telemedicine service (Physicians, N=25) - multiple-choice question

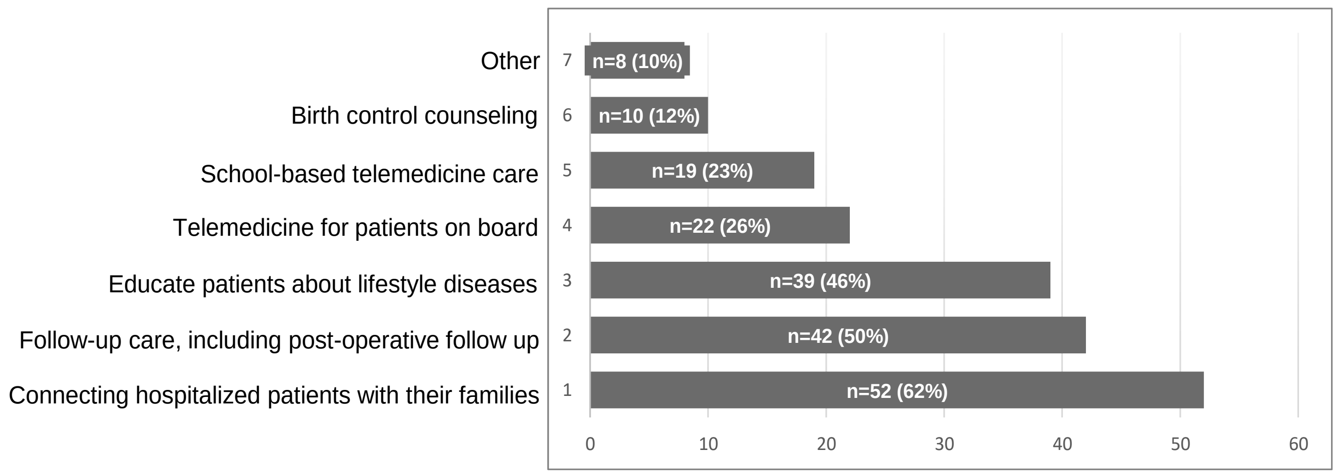

Figure 4. Issues that require telemedicine utilization (ordinary people, N=84) - multiple-choice question

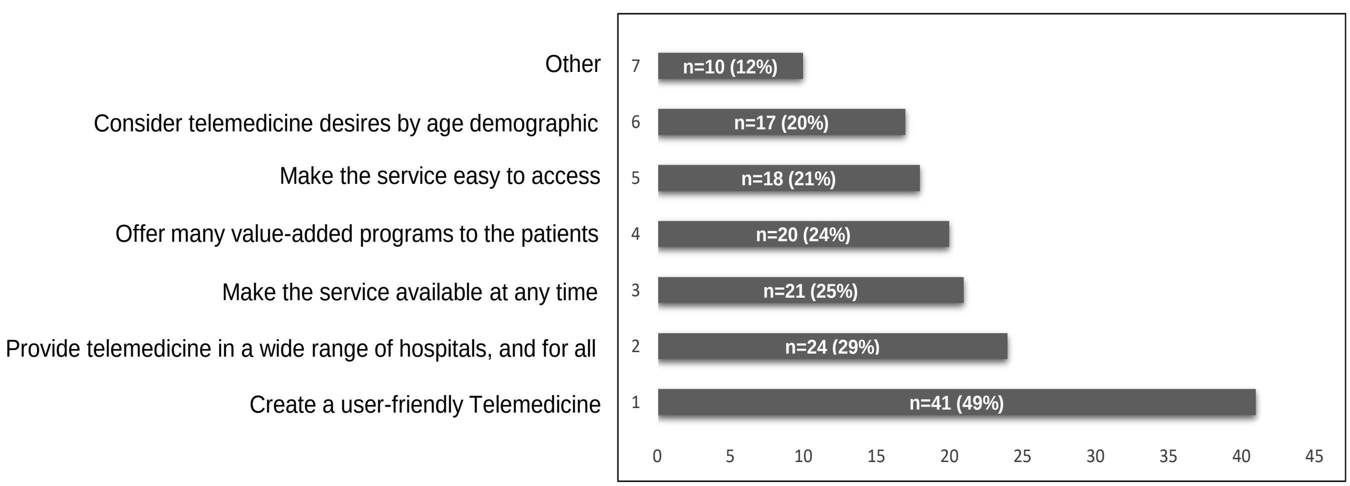

Figure 5. Key actions to improve current telemedicine program (ordinary people, N=84) - Multiple-choice question

P # 7 *"There is a necessity to promote telemedicine in the unpopulated/remote area in Japan".*

P # 24 and 25 *"Telemedicine should be more widespread in order to prevent infections and improve the efficiency of medical treatment. It is not very popular because many elderly people are not familiar with ICT. Therefore, ICT education for both elderly doctors and patients is needed".*

- Recommendations for raising telemedicine awareness:

P # 4 *"Patients broadly should know the merit and demerit of telemedicine and accept it".*

P # 17 *"Unique and advanced marketing strategies should be established to increase the patient awareness of telemedicine, such as the successful approach which is used for 'generic".*

- Recommendations about the regulations and facilities:

P # 3, 17 and 20 *"It is necessary to put strict rules and high-quality clinical practice guidelines to avoid any crimes or medical malpractice with telemedicine'.*

P # 20 *"All Japanese, especially politicians and lawyers should be fully aware of the telemedicine risks".*

P # 5 and 20 *"About the issue of low practice fee, the payments for telemedicine are better not covered by the health insurance, and allow doctors to set the prices freely. Furthermore, subsidies are needed. Cheap refund for hospitals, implementation and running cost. Medical fee should be increased for hospitals".*

P # 1 *"Telemedicine should maintain the same income as F-to- F meeting".*

P # 13 and 20 *"Policies of hospitals and equipment for telemedicine should be well prepared to use the service as one of its treatment tools".*

E. Usability requirements for a Telemedicine Meeting

Regarding the most suitable and trustful healthcare delivery model, the survey results revealed that the majority (74%) of participants in the first group preferred home-based telemedicine, while 12 (14%) participants chose mobile medical clinic, and a few (12%) participants selected the hospital-based telemedicine. Regarding the better mode for communication, we found that the majority (73%) of participants preferred video call, while 17 (20%) participants chose voice call, and a few (7%) participants selected "other". About the most adequate device for a telemedicine visit, the majority (38%) preferred smartphone "using a video call service", while 30 (36%) participants chose PC/tablet, about 24% of participants preferred smartphone "a voice call only", and a few (2%) of them chose "other" (see Figure 6).

On the other hand, the result of online interviews with 25 physicians detected that 14 (56%) doctors stated the necessity to improve their ICT skills, while 13 (52%) of them want the opportunity to experience first-hand what telemedicine is all about. Furthermore, 8 (32%) doctors stated other issues, such as getting the agreement of administrative staffs to practice the service in the hospitals, while 6 (24%) doctors wanted to find ways to train the staff on a shortened time. About 4 (16%) of doctors wanted to improve their online communication skills with patients (see Figure 7).

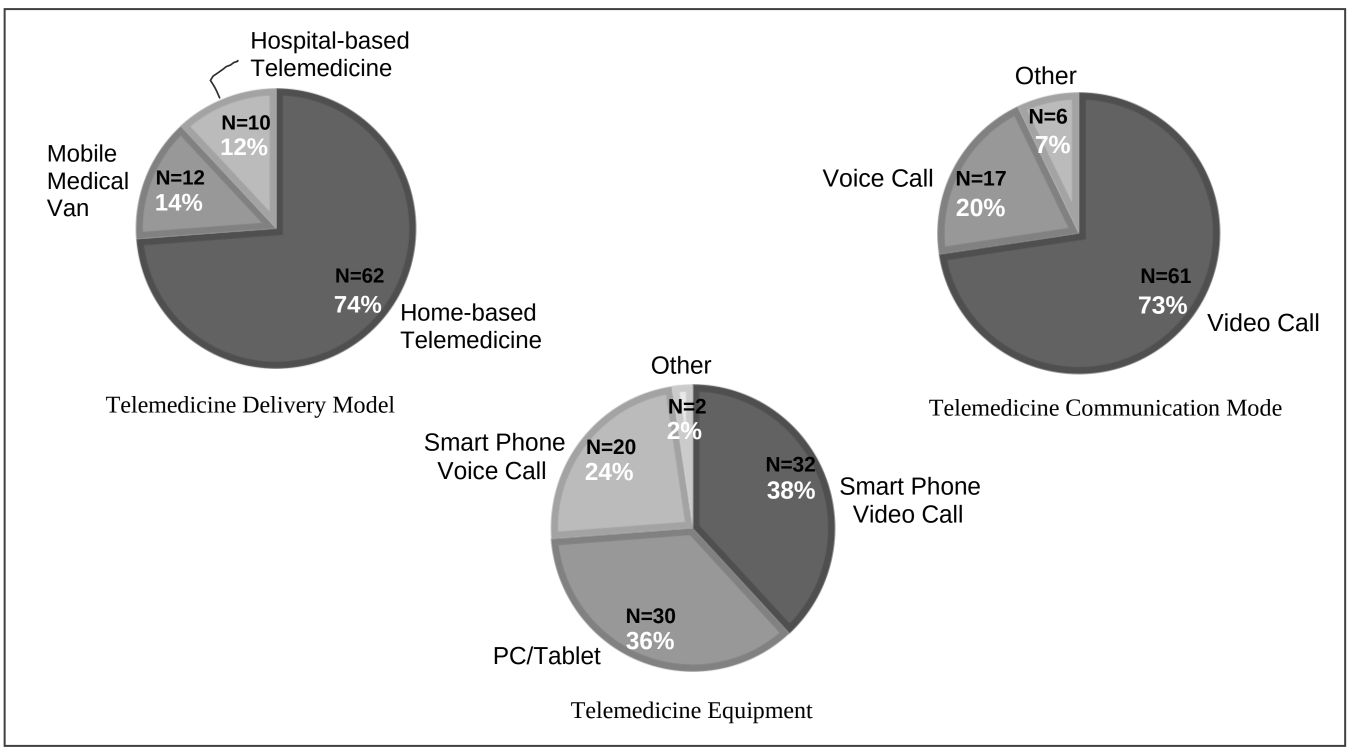

Figure 6. Best model of telemedicine usage (ordinary people, N=84)

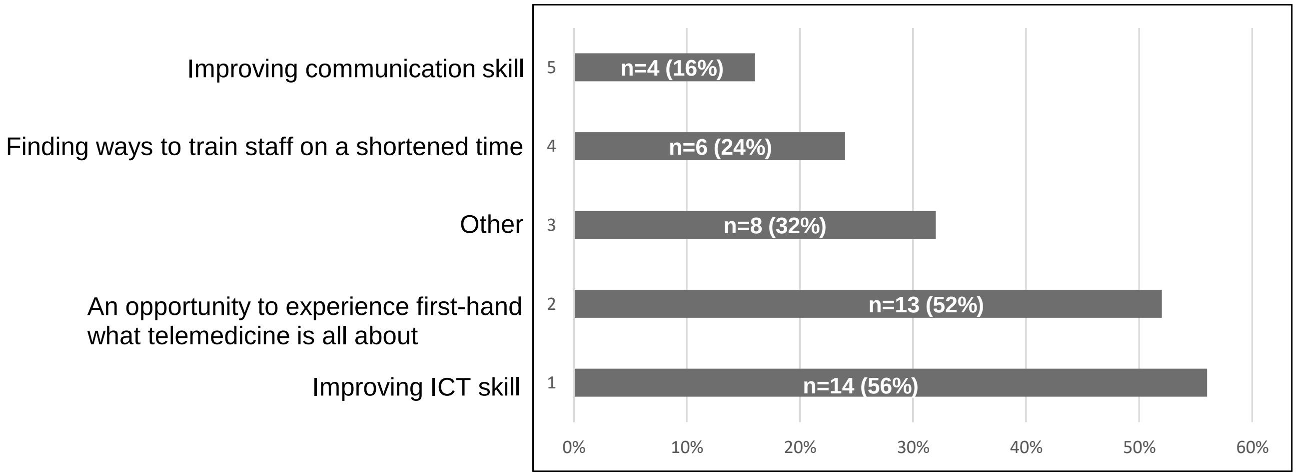

Figure 7. Usability requirements for a Telemedicine Meeting (Physicians, N=25) - multiple-choice question

IV. Discussion

Telemedicine services have the advantage of ensuring the health of inaccessible local residents and increasing convenience [8] [9]. Studies have shown that remote monitoring approaches are as effective as – and in some cases better than – in-person care for many chronic conditions [10] [11]. However, all the participants in this study, except three doctors, were not telemedicine users, even in a state of public health emergency due to the SARS-CoV-2 outbreak. Further, less than half of the participants from each group expressed their willingness to use the telemedicine service at present. In Japan there is a strong cultural bias towards face-to-face consultation, but the servicing rural and remote areas by doctors is increasingly difficult so there is an urgent need to increase the uptake of telemedicine [2]. These may confirm the viewpoints and recommendations of some physicians (P # 2, 3, 7 17, 23 and 24) on the necessity to establish innovative strategies for increasing the awareness and use of telemedicine.

In terms of telemedicine growth and development, studies reported that the service should deliver care that respects the patients' preferences and values - responds to needs in a person-centered manner [12] [13].

Based on the participants' responses, there are two approaches to potentially increase the use of telemedicine in Japan. First one aims to expand telemedicine capabilities. This is by identifying community issues and concerns that can be addressed through online care services. In other words, it is better going beyond traditional home diagnostic and monitoring activities to include further medical care forms where the individuals' abilities are restricted.

The survey results revealed that most (62%) participants in the first group indicated that telemedicine is a good tool for virtual visits to inpatients by their loved ones and/or conducting remote follow-up meetings with the family members who are unable to be with their patients at hospitals. The same suggestion had been stated by the majority (40%) of physicians participating in this study.

The second approach is about understanding people's requirements, preferences and views to improve a telemedicine platform. Based on the responses of first group, there are 6 key actions suggested to higher use of a telemedicine service.

Regarding the first action, the majority (49%) stated the importance of creating telemedicine equipment as user-friendly as possible. The usability issue is one of the seven core principles that underlie the development of successful telemedicine systems [14]. Furthermore, to make a telemedicine easier and safer, be mindful of the importance of site in which virtual encounters occur [12].

The survey results indicated that most participants preferred to conduct a telemedicine appointment at home by using video call over the smartphone. Similar findings showed in another survey that the majority of Japanese participants preferred video call with supplementary text message as a communication tool used for telemedicine [15].

On the other hand, studies pointed out that home-based telemedicine system via video conference can be of great benefit to patients in terms of convenience, reliability, health care availability, and cost savings. However, there are some issues affecting the efficiency of this system and should be well considered and addressed, such as privacy and security concerns, patient age, patient and healthcare professional's capabilities to use digital technology, Internet speed, network signal, audio quality, and technological compatibility [16] [17] [18]. In addition, a recent study indicated the necessity of the apps being easy to use for patients and staff, providing smooth access to important functions [19]. Regarding this point, further study stated that a user-friendly device which is easy to use by patients with low digital literacy is helpful, and a system allows medical personnel to remotely control the equipment could be an option [11].

Generally, usability is an important key to the successful implementation of telemedicine which is why the majority (56%) of physicians participating in the study indicated the need to improve their skills in using the ICT system, while some (P# 24 and 25) of them stated the need to educate the ICT among older adults (including physicians and patients).

Second action, 24 (29%) participants suggested providing the telemedicine services in the greater number of hospitals/clinics. In Japan, there is a slow spread of telemedicine in the hospitals. A high percentage of hospitals are not offering the service due to many issues, such as the lack of infrastructure and uncertainty about reimbursement [20]. This was also indicated by some doctors (P# 1, 5, 13 and 20) through the interviews. A study reported that among the 110,898 medical institutions that exist, the number of medical institutions implementing telemedicine increased slightly from 10,812 (9.7%) in April 2020 to 16,202 (14.6%) in June. Of this number, only 6,801 (6.1%) medical institutions implement telemedicine for a patient's first visit [21]. Lack of telemedicine use in the hospitals is not only limited to the clinical services (including remote patient care), but also to the non-clinical activities (such as medical education, management meetings, provider training, etc.). A recent study pointed out that international telemedicine conferencing is not sufficiently active in Japan, even though the installed equipment and technical expertise of technical staff in telemedicine are adequate [22].

The third action is about the service availability seven days a week. The current study findings showed that twenty-one (25%) participants requested to offer telemedicine services for patients at any time, day or night. This might be because there are sometimes difficulties to find an appropriate major hospital/clinic to visit in case of an emergency in Japan [23] [24]. Confirmation on that, 65 (77%) participants would prefer to use telemedicine services in a state of a personal emergency.

The fourth action, 20 (24%) participants recommended offering many value-added programs to the telemedicine patients as a part of their wellness programs. Regarding the fifth action, 18 (21%) participants clarified the importance of fast Internet speed for transmitting patients' files, records, pictures, and videos. A study reported that 18 factors inhibit the dissemination of telemedicine service in Japan, including network speed [25]. Most of the telemedicine applications require a high speed and reliable Internet bandwidth to run smoothly. Unreliable and low wideband Internet pose barriers in smooth delivery of telemedicine service [26].

Last action, 17 (20%) participants stated the necessity of considering telemedicine desires by age demographic because not all generations have same requirements towards telemedicine. A study reported that age plays a large role in consumer healthcare trends and telemedicine usage. Understanding consumer telemedicine trends by age group may be the key to increasing awareness and the use of telemedicine [27].

Based on the answers of the respondents, it can be said that telemedicine has not significantly spread in Japan despite the COVID-19 pandemic. The results of this study detected that it would be better to incorporate telemedicine service in our lives, rather than just focusing on medical consultations. This is by using telemedicine tools to address the issues of health care that concern the society. Furthermore, there are some issues that obstruct the growth of the service at present. Therefore, the answers of two groups of participants revealed that the telemedicine service is likely to be used more by considering certain actions. In this study, the needs and interests of each group have influenced the proposed actions. The participants in first group recommended specific actions related to the service usability, availability, value, and accessibility, while the suggested points of second group are related to the service awareness and facilities, as well as legal and business issues.

Overall, it can be stated that telemedicine success begins with the individuals' satisfaction. Stakeholders will start demanding more use of telemedicine that is when the service satisfies their needs and interests.

Regarding the limitation of this study, the survey was conducted with limited number of Japanese participants. The results cannot be generalized beyond the participants of a study. The participants expressed their own perspectives to develop the current telemedicine platform, and these may not express views of the majority of Japanese people.

V. CONCLUSION

Although telemedicine brings important benefits to promote wellness, prevent disease, and enable the home management of chronic conditions, it is still relatively uncommon to use in Japan. This study discussed the stakeholders' perspectives on the use of telemedicine. It investigated the willingness of Japanese people to use telemedicine, and in what situations/cases it is preferable to use for. It also identified two approaches to promote the use of telemedicine services.

The first approach aims to expand the scope of telemedicine, so as to address many issues which concern the society. Regarding the second approach, it focuses on developing the telemedicine service by understanding the stakeholders' views and needs. Based on valuable feedback of the participants from the general public, 6 actions are suggested to improve a telemedicine platform, and possibly raise the rate of its usage.

The key actions are concerning telemedicine usability, availability, value, and accessibility. Furthermore, recommendations have been made by the medical doctors about telemedicine awareness and facilities, as well as legal and business issues of the service.

On basis of the above findings, further studies are needed to explore the demands of different groups of individuals, such as older adults. Using larger and more diverse population samples will be valuable to establish the inclusive telemedicine service that fulfills the basic needs of the society.

ACKNOWLEDGMENT

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Quantitative Approaches for Detecting Early Childhood Developmental Disorders using Wireless Sensors and Mobility Data

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***Abstract*— As estimated by the World Health Organization (WHO), 5% of the world's children population are diagnosed with an early developmental disability such as autism and cerebral palsy. State-of-the-art clinical diagnostic procedures are predominantly dependent on observational assessment by a trained physician. Physicians assess the severity of the disability by observing the child as well as by considering the feedback from the parents. However, as the final decision is completely dependent on the observer the procedure becomes subjective and does not provide an accurate decision. Moreover, such approaches are time-intensive and require enormous human effort. Hence, it is essential to explore the alternative opportunities that provide an accurate assessment. Recent studies show that abnormal motor skills are often the initial signs of later developmental disorders. This paves the way for exploring alternative opportunities to identify the disease in the early stages of childhood. Although different methods for collecting neonate motor data have been explored in the past, improvements in sensing technologies facilitate convenient as well as unobtrusive methods to collect the mobility data even from the infants and be able to detect the abnormality in the motor movements. Since wearable devices are tiny and easy to use in collecting motor data from neonates, it is feasible to distinguish abnormal motor development from normal motor development. Thus, mobility data collection from an infant using a wearable sensor is beneficial in the early diagnosis of developmental disabilities like cerebral palsy. Our main contribution to this study is to present the analysis of various wearable sensor-based motor assessment methods in predicting childhood disorders. This article first presents some of the existing clinical diagnostic procedures and then elaborates on mobility-based quantitative assessment methods. Furthermore, this document presents various crucial mobility parameters associated with identifying childhood disorders.**

Keywords- mobility; childhood developmental disorder; wearable sensor.

I. INTRODUCTION

In recent years, the prevalence of developmental disorders among children is rising at an alarming rate. Autism Spectrum Disorder (ASD), Cerebral Palsy (CP), and Attention Deficit Hyperactivity Disorder (ADHD) are the most common disorders that infants are affected in the USA [1]. According to the World Health Organization (WHO), around 5% of the world's children population aged under 14 years are afflicted with a moderate to severe disability [2]. Early childhood developmental disorder is one of the primary causes of children being referred to primary healthcare clinics [3]. Chronic or perpetual delays in one or more motor functions of the child can be treated as a development disorder [4]. The onset of the disability may occur regardless of racial, ethnic, and socioeconomic groups. The manifestation of motor disability is caused by atypical brain development. Yet, specific reasons for atypical brain development are not known [5]. Research shows that preterm birth and pregnancy complications that occur in the perinatal period may affect the brain. Consequently, babies born in this category are at risk for neurodevelopmental impairments [6]. Additionally, low birth weight and infections during pregnancy are a high risk for several developmental disabilities. According to the study conducted by National Health Interview Survey (NHIS) in the United States, the growth of childhood disorders has increased to 17% between the years 2009 and 2017. Also, one out of six children between the age groups 3 and 17 years have one or more disabilities [7]. Furthermore, ADHD, ASD, and CP are the common disorders found among children and boys were more likely to be in the vulnerable group than girls [4].

Although there is no standard laboratory test for identifying developmental disability in high-risk neonates, several researchers have proposed diagnostic guidelines for each disorder individually. For instance, Case-Smith introduced Posture and Fine Motor Assessment of Infants (PFMAI) for identifying developmental delays by observing neonate's motor movements [8]. Similarly, Prechtl's assessment for detecting CP and The Alberta Infant Motor Scale (AIMS) for assessing gross motor development are some of the observation-based diagnostic methods [9][10]. Nevertheless, most of these procedures offer subjective evaluation and are solely judged by a trained practitioner. Furthermore, children need to be taken to specially designed laboratories multiple times. Therefore, it is crucial to implement an objective technique that can accurately identify the developmental disability.

The evolution of fine and gross motor skills in children with atypical neurodevelopment is more cramped than in children with typical neurodevelopment. As a result, affected children do not acquire smooth limb movements but rather rigid and nonsynchronous [11]. Often, delays in acquiring sufficient motor movements are the early signs of later developmental impairment. Hence, an infant's motor assessment can be a potential parameter for the early diagnosis of the disability. Moreover, significant research is going on towards the assessment of an infant's motor function as a method to detect developmental disorders, such as CP, and ASD [4][7][11]. The sooner the disorder is diagnosed the better the possibility for effective intervention therapy.

The main motivation of this study is to describe some of the existing clinical procedures to determine the onset of the disability. Then elaborate on wearable sensor-based diagnostic methods in identifying the various developmental disorders by utilizing the motor movements of infants. In this document mobility and motor, movements are used interchangeably. The remaining sections of the document are structured as follows. In Section II, the study methodology is discussed. Section III explains various qualitative assessment methods. different types of wearable devices used for mobility data collection are elaborated in section IV. In section V, the mobility-based quantitative diagnostic approaches are presented. Important mobility parameters that have been explored by the scientific community are highlighted in section VI. Under Section VII, various aspects of mobility-based assessment methods are elaborated. Finally, Section VIII concludes with a summary of this work.

II. METHOD

In the past decade, there has been a substantial rise in the quantitative assessment of motor dysfunction by attaching tiny sensors to neonates' upper and lower limbs. Abnormal movements are characterized by repetitive, stereotyped movements, rigid movements due to lack of smoothness, and unusual gait patterns [6]. These atypical patterns are distinguishable by processing the mobility data collected from the sensors attached to a child's limb. Researchers have also concluded that abnormal movements are strongly correlated to their abnormal brain development [12]. The goal of motor assessment is to quantify the degree and range of motor disability and predict whether the child falls under the stage of Typical Development (TD) or At Risk (AR).

The primary purpose of this document is to review the various mobility assessment methods that were employed for diagnosing early childhood developmental disorders. At first subjective methods are discussed then wearable sensor-based assessment methods are elaborated. For this study, literature has been chosen, which includes different aspects of early childhood disorders. The literature study criteria are explained in detail in Fig. 1.

III. BACKGROUND

This section illustrates various subjective methods that detect developmental disability in early childhood. These methods can be broadly categorized into two types: milestone-based assessment methods and observer-dependent methods. To discuss further three generalized developmental stages are defined.

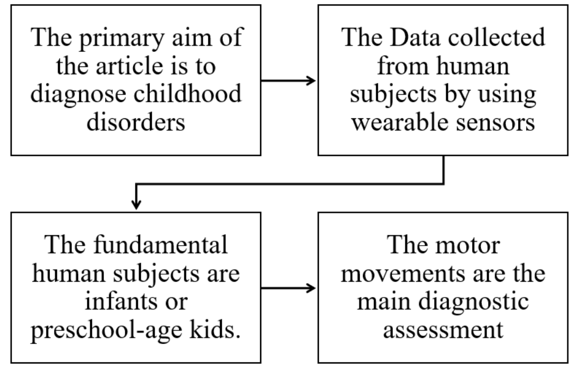

Figure 1: Study procedure

At-Risk (AR): Neonates born preterm and with pregnancy complications are considered At Risk (AR) of developing aberrant motor function and eventually likely to be diagnosed with developmental disorders including CP [4].

Typically developing (TD): Infants with normal limb movements are classified as Typical Developing (TD) [4].

Neurodevelopmental disorder (NDD): Children who are already diagnosed with any developmental disorders like CP, ASD, and ADHD are categorized as infants with NDD [13].

A. Milestone-based assessment Methods

Milestone for a child is considered as what most babies do by that age. Milestone-based assessment is the simplest method that facilitates in early detection of the disability. The development in the early infantile years is crucial for the lifelong growth of every child. Therefore, the first 36 months are very important to check and recognize if there is any lag in acquiring any development [14]. Typical growing children develop in five major categories: (1) cognitive, (2) social and emotional, (3) speech and language, (4) fine motor skills, and (5) gross motor skills. Delay in acquiring one or more of such skills can be considered a developmental disorder.

According to the CDC [4], TD child reaches certain developmental milestones as they grow. For instance, in most, the 6 months old babies begin to roll over and recognize their parent's faces. Likewise, a 12-month-old toddler should be able to sit without any help and exhibit variable limb movements. However, AR infants lag in acquiring one or more such skills. Trained physicians and practitioners recommend using developmental surveillance and screening process as an early intervention to identify the disabilities [14]. It is a longitudinal and continuous process where infants' growth is carefully observed. Often, clinicians assess the type and severity of the disability by integrating the feedback questionnaire from parents as well as the child. Though it is the initial diagnostic method used by the practitioners, it is time-intensive and requires continuous monitoring of the child for several days.

Moreover, the probability of missing certain guidelines is very high. Hence, clinicians are interested in developing standardized clinical guidelines that can identify the disorder as well as quantify the severity of the disorder.

B. *Observation-dependent Methods*

Traditional assessment is heavily dependent on visual observation by a trained physician. Sometimes physicians prepare a questionnaire and assess the level of abnormality by integrating the feedback from the parents and/or the child. In such a scenario, parents might be unaware of specific symptoms that the child is suffering, and the child may not be able to give precise feedback as adults. Hence, the decision-making becomes more complex. Additionally, existing clinical methods, such as analysis of neuroimaging require a trained consultant physician. But reliability and accuracy are largely depending on the expertise of the consultant. Besides the inherent complexity in judging the presence of the disorder, estimating the severity of the illness is far more challenging. The inception of qualitative assessment of the infant's nervous system is indeed a breakthrough in the diagnosis of developmental disorders.

The Alberta Infant Motor Scale (AIMS) [9] is one of the early observational scales to assess the neonate's gross motor function. In this method, a rating will be calculated based on the infant's performance in weight-bearing, posture, and antigravity movements. This method can be used only for babies under 18 months of age and the observer needs extensive training in the respective assessment. Prechtl et al. [10] proposed another observation-based systematic methodology termed General Movement Assessment (GMA) for diagnosing CP. They have postulated that the quality of General Movements (GMs) is cramped and lacks smoothness over time due to impaired brain development. The absence of GMs may be observed in the video recording of an infant. This approach also does necessitate training by experts. In another experiment [15], Heineman et al. developed a video-based mobility evaluation technique, the Infant Motor Profile (IMP), that can differentiate between kids between TD and AR neurodevelopment. The downside of all these methods is that it involves an enormous human effort to examine the video recording for accurate prediction. Melbourne Assessment of Unilateral Upper Limb Function-2 (MA-2) is a standard reference tool to measure the quality of upper limb movements in kids with atypical brain growth aged between 2 to 15 years [16]. Moreover, scoring is estimated based on how a child performs 14 test activities including pickup and release of some objects. Likewise, there are numerous subjective motor assessment methods including the Bayley Scale of Infant and Toddler Development [17], Neuro Sensory Motor Development Assessment (NSMDA) [18], and Test of Infant Motor Performance (TIMP) [19].

However, rating-dependent approaches have various shortcomings. (1) Assessment is entirely observer-dependent. Consequently, there is a high probability that the observer is wrong in his estimation. (2) Evaluation is time-intensive and consumes immense human effort. (3) The observer is required to be trained in advance with the necessary skills to make an optimal conclusion. After the training, it takes substantial time to acquire proficiency in the diagnosis. (4) Patients must visit the physicians and laboratories frequently. (5) Often, laboratories must have a specialized environment and equip with expensive tools. (6) Monitoring the rehabilitation of the affected infants is challenging because of the dependency on the observer. (7) Children's attention span is very limited, and so they can easily get annoyed with cumbersome instructions. Hence, to overcome these limitations, it is essential to have an observer-independent approach.

IV. MOBILITY AND DEVICES

Characterizing the atypical motor movements including repetitive and stereotypical patterns is crucial in the early diagnosis of neurodevelopmental disease. A qualitative examination of neonate movements necessitates a special skill set and the outcome varies from observer to observer [20]. To fill the gap, sophisticated systems, such as stereo photogrammetric movement analysis, gaze-tracking devices, and 3D motion tracking with passive markers [21] were introduced. Yet, these methods require an expensive structured setup with many wires and sensors to monitor the baby's physical movements. Wearable technology made it possible to collect the movement data by attaching tiny sensors to the body parts of the infants without major disturbance.

In recent times, Inertial Measurement Units (IMUs), also known as inertial sensors have been increasingly explored by numerous researchers. Typical IMUs comprise of accelerometer and gyroscope and occasionally include a magnetometer. Nevertheless, many scholars have employed an accelerometer-based sensor to acquire infants' arm and leg movements [6][22][23]. Wearable instruments are suitable for monitoring the limb movements of infants because of their flexibility in sensor placement, adaptability, and power efficiency. Since the human subject is an infant, sensors are usually embedded in an appropriate peripheral, such as leg warmers [12], and wristwatches [24]. In some studies, skin-adhesive sensors have also been used [25]. Although the device has a variety of sensing technology, the aim is to collect the movement data unobtrusively without creating considerable discomfort for the babies. Therefore, wearable sensors are efficient for the objective assessment of children's movements. Table 1 shows various wearable sensor devices employed in collecting mobility data from children.

Nowadays, wearable devices are compact and come with internal storage as well as a provision to connect and upload the data to cloud storage on the go. Most of the devices are battery-operated, eliminating cumbersome wires and cables. When multiple sensors are included in the data collection process, then all the sensors must be actively synchronized

TABLE 1: Various wearable sensors employed in collecting the mobility data

Reference	Sensor name	Components	Make	Sensor placement	Type of data	Type of movement
[6]	Cloth band sensors	Accelerometer	Custom designed	Wrist, ankles, and forehead	Raw sensor data	Limb and head movements
[12,26,28, 27, 31]	APDM Opal sensor	3D-accelerometer, 3D-gyroscope, and 3D-magnetometer	APDM	Left and right ankle	Raw sensor data from all directions	Leg movements
[21]	WAMS	Inertial-magnetic MAG3 sensor, Analog-to-Digital Converter	Custom designed	Wrist and ankle	Raw channels converted by ADC	Wrist and ankle movements
[23]	ETH orientation sensor	Accelerometer and Gyroscope	Custom designed	Predefined body movements	Raw sensor data	Limb and head movements
[24]	Bracelet sensors	Accelerometer	Custom designed	Both wrists	Raw sensor data	Right and left wrist movements
[25]	MetamotionC sensing board	Accelerometer, Gyroscope, and Magnetometer.	Mbientlab	Wrist, ankles, and forehead	Raw sensor data	Limb and head movements
[29]	Actiwatch	Modified Accelerometer	Mini Mitter	Right ankle	Activity count	Right leg movements
[30]	Axes of the accelerometer	Accelerometer	Freescale semiconductor	Hands and ankles	Raw sensor data	Both hands and leg movements

throughout the duration. It then allows data to be collected continuously from all sensors, even outside the laboratory environment, such as at home. Primarily, these devices are used to record upper and lower limbs that will help characterize the disorder. Although numerous instruments, such as gaze tracking devices, are available to collect mobility data, not all may be suitable for infants. Furthermore, setting up such a piece of equipment requires a well-structured and perfectly controlled laboratory environment. The wearable devices are an ideal replacement for infants that can facilitate accurate measurement of motor movements [21]. In addition to this, wearable devices are wireless and create a friendly ecosystem for little kids. Wearable devices come at affordable prices that make it easy to attach multiple sensors simultaneously to record all the baby's movements. Fig. 2 presents the convenient body locations where sensors can attach. And different impaired movements are shown that are characterized as aberrant motor movements exhibited by the disordered children.

V. MOBILITY-BASED ASSESSMENT METHODS

Measuring abnormality from the child’s movements is an important clinical task as it reduces the significant human effort in identifying the impaired motor skills. Further, it helps physicians to come to an objective conclusion. With the latest advancements in wearable devices, it has become easy to attach them to infants and collect the data continuously. Various quantitative motor assessment studies are summarized in Table 2. This study includes the research that has employed wearable sensors and finds the quantitative measurement of the children's motor movements.

A few scholars had endeavored and developed unobtrusive and non-invasive wearable instruments suitable for infants and toddlers. As early as 2008, Campolo et al. [21] prototyped a wearable sensing system for monitoring the upper and lower limb spontaneous movements of premature babies. Their sensing instrument can be used in infants as young as 2 weeks. They have hypothesized that abnormal movements are the early signs of later developmental disorders, such as ASD. Redd et al. [25] carried a pilot project on a single healthy born infant to assess the General Movements (GMs) and Fidgety Movements (FMs) [10]. They have built a wearable monitoring system with an array of sensors to acquire the infant movements for both the short and long-term. Their results show that the absence of variability in GMs and FMs might be the early sign for the manifestation of neurodevelopmental disorders, such as CP. Nonetheless, they have experimented with only one healthy infant.

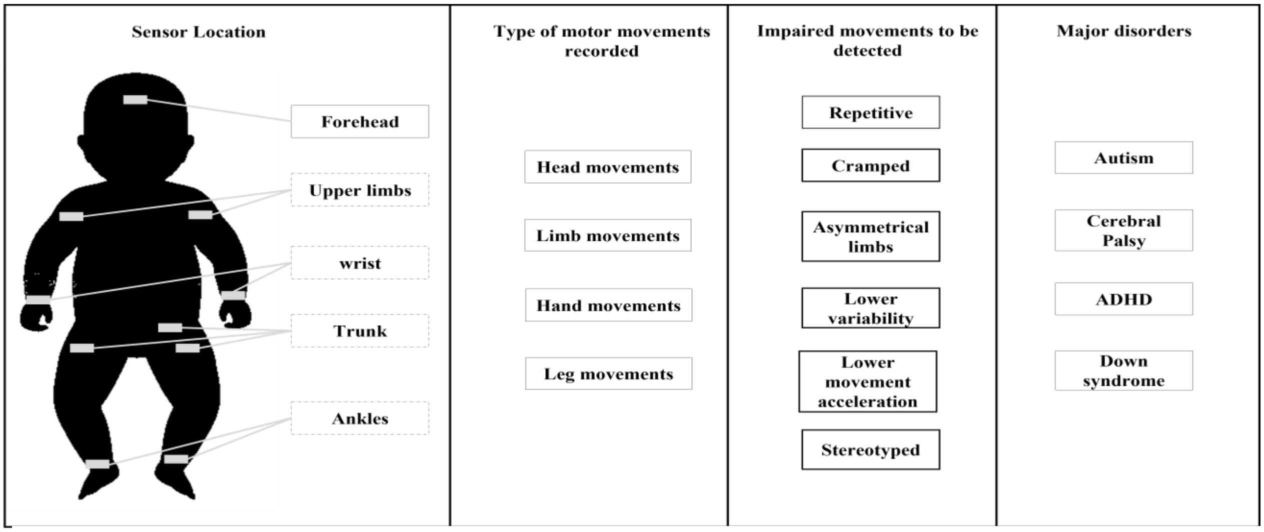

Figure 2: Wearable sensors based quantitative diagnosis

TABLE 2: SUMMARY OF MOBILITY-BASED ASSESSMENT METHODS

Reference	Purpose	Sensor	Sensor placement	Wear time (in hours)	Setting	Disorder	Movement type	Subjects	Age (in months)
[6]	Predict impaired motor activity	Accelerometer	Head, ankles, and wrist	1	Clinical	CP	Spontaneous head, leg and arm movements	10 AR	<3
[12]	Classify TD and AR	IMU	Ankles	8-13	Natural	NA	Spontaneous leg movements	12 TD 19 AR	1-15
[21]	Early diagnosis	IMU	Wrist and ankles	NA	Clinical	ASD	Spontaneous leg and arm movements	NA	NA
[22]	Measure variability of movements	IMU	Ankles	8-13	Natural	NA	Spontaneous leg movements	11 TD 20 AR	6-9
[23]	Predict motor disorder	Accelerometer and gyroscope	Trunk, upper and lower limbs	4	clinical	CP, stroke	Predefined body movements	4 AR	9-12 years
[24]	Clinical vs motor assessment	Accelerometer	wrist	75	Natural	CP	Spontaneous upper arm movements	26 TD 26 AR	1-17 years
[25]	Diagnosis CP	IMU	Forehead, ankles, and wrist	1 min	Clinical	CP	Spontaneous head, leg, and arm movements	1 TD	3-5
[26]	Classify TD and AR	IMU	Ankles	8-13	Natural	NA	Spontaneous leg movements	12 TD 19 AR	1-16
[27]	Quantify leg movements	Inertial sensor	Ankles	8-13	Natural	NA	Spontaneous leg movements	12 TD	1-12
[28]	Diagnose ASD	IMU	Ankles	8-12	Natural	ASD	Spontaneous leg movements	5	3-12
[29]	Assess leg movements	accelerometer	Right ankle	48 hrs. x 4 times	Natural	DS	Spontaneous right leg movements	8 TD 8 AR	3-6
[30]	Diagnose CP	Accelerometer	Ankles and wrist	20 min	Clinical	CP	Spontaneous leg and arm movements	19 TD 4 AR	<10
[31]	Number of days required for assessment	IMU	Ankles	5 days	Natural	NA	Spontaneous leg movements	16 AR	2-14

Typically developing (TD) neonates demonstrate rich leg movements by embedding tiny sensors inside custom-designed leg warmers. Moreover, the researchers aimed to classify the group of infants into TD or AR from the day-long (8-13 hours) leg movements data. They also analyzed sensor data recorded from AR infants and were able to distinguish between AR babies with poor and good development. In [26], Goodfellow et al. developed binary classification algorithms to predict whether the child is TD or AR. In this approach, a group of 22 infants aged between 0 to 12 months was divided into two groups 0-6 months and 6-12 months. Then, the researchers extracted two sets of features for each group and found a significant difference between TD and AR mobility data of 0-6 months than from 6-12 months. Their findings prove the importance of early childhood diagnosis. Often, it is critical to categorize between TD and AR during early infancy. Abrishami et al. [26] quantified infants' spontaneous groups as 0-6 months and 6-12 months. Then, extracted two sets of features for each group and found a significant difference between TD and AR mobility data of 0-6 months than from 6-12 months. Their findings prove the prominence of early childhood diagnosis.

Similarly, numerical estimation of abnormal mobility has also been studied in the past as it helps in distinguishing both healthy and impaired infants. One of the early experiments [6], utilized a simple accelerometer sensor and was able to collect the data from the premature neonates recruited from the NICU, who are potentially at risk of CP. Then, by extracting features and applying the machine learning technique including Decision Trees. The researchers were able to recognize the abnormal movements namely Cramped-Synchronized General Movements (CSGMs) [10]. According to Prechtl's assessment for CP [27], the presence of CSGM is an early marker for lateral developmental disorders. Wilson et al. [28], formulated Motion Complexity (MC) by measuring the variability from the infant's leg movement data. They conjectured that infant with lower MC is at risk (AR) of disabilities, such as ASD. Moreover, AR subjects compose lower motion complexity compared to TD subjects because their actions are repetitive and stereotyped. Smith et al. [22] proposed Sample Entropy (SampEn) as a function to measure the variation and repetition in kids' leg movements. Additionally, SampEn is lower for infants with developmental delays than normal infants. A different experiment carried out by Hoyt et al. [24], assessed only upper limb movements and recommended two metrics: The Use Ratio (UR) to measure the quality of using both arms and the Mono Arm Use Index (MAUI) for quantifying intensity and frequency of each arm. Their results signify that UR and MAUI are lower for typically developing children and higher for children with developmental delays.

Furthermore, many scientists are interested in studies specific to a particular disorder like CP and Down Syndrome (DS). McKay et al. [29] conducted a mobility assessment of a group of infants with DS and without DS. Using an activity monitor attached to the baby's right ankle measured leg activity and sleep patterns at 3,4,5, and 6 months. Their statistical analysis observed a significant group difference between the infants with DS and without DS with respect to their motor components. Strohrmann et al. [23] acquired mobility data from four children (2 diagnosed with CP and 2 with stroke) undergoing rehabilitation. In this work, they were invited to perform a set of predefined motor tasks and the progress in rehabilitation therapy was measured using extracted features including smoothness in the upper and lower limb movements, and coordination between both arms. Another study [30], proposed an objective assessment methodology to diagnose CP from the spontaneous leg and arm movements of newborn babies. Their method is built on a decision tree classifier algorithm and achieved ~90% accuracy. Further, they have posited that their methodology can be easily adapted by the clinical practitioners and helps to monitor the progress of rehabilitation.

A different experiment performed by Deng et al. [31] assessed the motor behavior of neonates to determine the minimum number of days required to characterize the ideal daily leg movement patterns of children who are at risk of developmental disorders. They hypothesized that two days of leg movement data is sufficient to accurately predict developmental disorders among the infants at risk. Smith et al. [27] developed an algorithm to measure the full day of leg activity and attempted to identify the relationship between the number of leg movements and the onset of walking. However, their test produced surprisingly unexplainable results as infants with a smaller number of leg movements began walking early than the babies with a greater number of leg movements.

VI. Discussion

This section presents the various aspects of mobility-based assessment approaches and discusses their strengths and weaknesses.

A. Mobility Parameters

Analysis of mobility data is central to the identification of abnormal motor movements, which are characterized as developmental disorders. Identification of abnormal movements begins with the collection of mobility data using wearable sensor devices. The raw sensor data generated by these devices are preprocessed to eliminate noise and unwanted information. Furthermore, the sensor data will be cleaned and transformed, which will be consumed by the feature extraction phase. Features are selected in a way that represents motor movements that allow quantifying the intensity of abnormality. Table 3 lists the various mobility parameters chosen by the researcher in identifying the abnormal movements.

From Table 3, although the objective of each study is to quantify the limb, wrist, ankle, and head movements to identify the abnormal movements, all the researchers have not used the same set of features. For instance, studies [12] and [28] have employed accelerometer-based sensors and extracted the duration of each ankle movement, peak, and average acceleration of a movement. On the other hand, a researcher in a study [6] has measured the maximum and

Table 3: Summary of mobility parameters

Reference	Mobility parameters	Purpose of assessment	Type of movements
[6]	Maximum and minimum of the upper and lower body, maximum of all limbs, Pearson correlation between left and right leg	Predict abnormal motor function	wrist, ankles, and head movements
[7,30]	Skewness, cross-correlation, Area out of standard deviation of moving average and area differing from moving average, periodicity, the Detection rate	Diagnose CP	Ankle and wrist movements
[12, 28]	Duration of a movement, peak acceleration, and average acceleration during a movement.	Diagnose ASD, Classify TD & AR	Left and right ankle movements
[23]	Task completion time, Mean value of movement intensity, movement intensity variation, dominant frequency, smoothness of movements, average rotation energy, range of angular velocity, synchrony of arm movements	Predict motor disability	Movement data from predefined tasks
[25]	Fidgety movements (FMs) and general movements (GMs)	Diagnose CP	wrist, ankles, and head movements
[26]	movement count, movement duration, average acceleration, and peak acceleration	Classify TD & AR	Left and right ankle movements
[27]	Acceleration and angular velocity	Quantify leg movements	Left and right ankle movements
[31]	Average leg movement rate, movement duration, average acceleration, peak acceleration	Minimum number of days required for diagnosis	Left and right ankle movements

minimum acceleration of body movements. However, most of the researchers utilized mobility data from the wrist and ankles. The duration of the movement is another common parameter utilized by most of the studies [7][12][28][30][31]. The motivation behind using duration as a feature is to quantify the difference between healthy and abnormal motor development. Children with developmental disorders perform lower-duration movements while healthy kids perform longer-duration movements. Unlike in other experiments, [23] did not extract the mobility features directly from the raw sensor data. Rather, subjects were asked to perform a set of predefined tasks, and then features are computed from the data recorded from those predefined actions and movements.

B. *Challenges in Data Collection*

Infant’s motor assessment using wearable sensors has been increasing over the last decade because of their miniature size and wearability. Also, sensors can be attached to any part of the body and have the ability to function in both a laboratory setting and a home environment. Nonetheless, unlike adults collecting data from kids is not as easy for several reasons. (1) Preparing an infant for data collection is challenging because they are fragile and require utmost care. If it is a lab environment, then room temperature must be adjusted to the comfort of the child [30]. Additionally, the parent must ensure essential daily routines, such as breastfeeding and diapering. So, the child is ready and performs desired spontaneous movements. (2) Children's behavior is unpredictable, so sensors can fall off or become loose, which can eventually add noise to the data stream. For this reason, in a clinical setting or home environment, either a parent or a caregiver must always be present to take care of the sensor positing during the data collection period [31][32]. (3) size and placement of the sensor are important to reduce the irritation to the child. The ongoing research shows that the average weight of each sensor ranges between 10 grams to 30 grams [12][24][25]. However, the sensor's positioning has limited choices as it needs to be placed on the arms and legs to measure the limb movements.

C. *Wear Time*

Although there is no evidence for precise sensor wear time required for accurate data analysis, numerous studies collect the data for more than one hour for an objective conclusion. As wearable technology is advancing, it is now possible that sensors can be placed in diversified products like leg warmers [12], which are comfortable for the infant. Hence, some scholars have embedded sensors in the form of socks, and wristwatches and were able to collect the data for 2 to 5 days. Nonetheless, according to the study conducted by Deng et al. [31], two days of sensor data of infants is sufficient to differentiate between typical and atypical movements pattern. Yet, further investigations are necessary to minimize the wear time.

D. Accuracy and Validation

Accuracy validation of an infant's motor assessment method is crucial for decision-making in clinical research. Irrespective of the methodology used for the assessment, it is essential to compare the results with ground truth to measure the accuracy of the model. Researchers are primarily depending on two types of accuracy validation approaches in the context of an infant's motor assessment. Each method differs by ground truth. (1) In this approach, the sensor data collection procedure is video recorded such that normal and abnormal movements are annotated by experts. This annotated data is used as ground truth to validate the accuracy [12][22][23][24][27]. Undoubtedly, it is one of the popular and fastest methods used in many studies. (2) Alternatively, some investigators follow up on the infant's health status after a few months to validate their inference of those who were classified as high risk. In a study [20], the authors assessed children's movement complexity patterns at 3,6, 9, and 12 months of age, however, follow-up was done at 18 and 36 months of age to validate their results.

E. Noise Elimination

Unfortunately, infant movement data recorded from the sensors is mostly accompanied by noise [27]. Especially, in the context of infants, the amount of noise induced might be higher than normal. Because the daily routine of every child frequently changes between sleep, waking, and active states. Besides, a child might experience discomfort for unknown reasons. Then, either parent or caregiver must pacify the child to resume the data recording. Thus, the presence of noise is inevitable in children's movement data. Due to the effects of noise, movement assessment derived from the noisy sensor data is biased and inaccurate. To remove noise from the movement data, investigators have employed different techniques. To eliminate outliers, preprocessing and normalization of the data are some of the popular approaches [15][23][27]. In this approach, raw data is normalized and standardized to align within either first or third quantiles. Alternatively, parents or caregivers to write down the activity log of any major change in movement [12][22]. For instance, the activity log records the sleep, wake, and play times of the child. This method helps to extract the data, that is relevant and useful based on the activity log.

F. Quantifiable Parameters

Quantitative measurement has been used by several researchers for the automatic assessment of impaired motor function. In contrast, some researchers have developed a quantifiable metric that can measure the level of motor impairment. Their main objective is to quantify the variability and repeatability of arm and leg movements as a unit that can be used to measure the degree of neuromotor control. An objective metric called Motion Complexity (MC) [28] was proposed for full-day mobility data acquired from the sensors attached to both legs. MC is computed from the duration of movement, peak acceleration, and average acceleration during a movement. MC is essentially a measure of the variability of the recorded leg movements. Their experimental results demonstrate that two kids from the sample of five subjects have lower MC scores than the other three kids and that they later developed ASD. Sample Entropy (SampEn) is another quantitative measure introduced in [22]. The researchers postulated that AR infants' SampEn values are significantly lesser than TD infants. Hence, SampEn may be a potential early marker to detect abnormal growth of neuromotor control. Hoyt et al. [24] computed two metrics from the sensor data of upper limb movements: Use Ratio (UR) and mono arm use index (MAUI). These two components measure the asymmetry between the two arms. They postulated that infants with neurodevelopmental deficits might not use both arms like normal children. Their study results corroborated their theory.

G. Spontaneous Movements vs Therapeutic Movements

While spontaneous movements are either leg or arm movements recorded during an infant's active playtime, therapeutic (pre-defined) movements are designed by researchers in collaboration with clinical expert physicians [23]. Pre-defined movements are straightforward to process because they are logged in a well-controlled lab environment and accurate movement is well known in advance. Whereas spontaneous movements require additional processing to extract useful features as well as suppress unnecessary noisy data [27][30]. Although the pre-defined movement processing technique is simple to use, scholars are mostly interested in spontaneous physical movements. Because the treatment of spontaneous arm and leg movements is more practical and accurate.

H. Upper vs Lower limb movements

For a typical human being, the upper limbs are most important for performing daily routine activities such as self-care and work. Conversely, it is always not true for infants because most of their daily routine is taken care of by their parents or caregivers. Thus, which limb movements are feasible for quantifying abnormal movements is a debatable question. In fact, unraveling the answer to this question also depends on another question, i.e., which limb movements are convenient to collect the mobility data to identify the disability. Table 2 clearly shows that most of the studies used sensors for either the upper limb or lower limb. However, the majority of the researchers were interested in recording the mobility data only from lower limbs [12][22][26][27][28][29][31]. Although they did not mention the specific reason for their decision to use only lower limbs, it might be more convenient than attaching the sensors to the upper limbs.

I. Variations in motor movement skills

Motor behavior of a growing child generally includes actions of every part of the body from head to toe. Although the development of fine motor skills is critical, they are usually established during the first 2 years of a child. At each developmental milestone [33], a child reaches a particular stage. For instance, most babies can sit at the age of 6-8 months without any support. The absence of such crucial milestones eventually turns into a developmental disorder. Impairment in the growth of motor skills hampers various aspects of daily life including eating and self-care. Abnormality in motor abilities reflects the onset of a developmental disorder such as Autism. Variation in motor movements is the early sign of identifying developmental disability [21]. As described in Background section III, a child can be categorized into one of the three stages: Typically Developing (TD), At-Risk (AR), and Neurodevelopmental Disorder (NDD). A TD infant is considered to be healthy and therefore demonstrates a full repertoire of movement skills. Their movements are variable and complex in nature. They perform a wide range of movements from head to toe. On the other hand, an AR kid is on the fence about moving towards the disability stage. Though they may not exhibit complete abnormality in their movements, by careful observation and assessment certain impaired movements can be noticeable. There may be rigidness and inactiveness in limb movements. Their hand and leg motion might be cramped. In such a scenario, it is critical to diagnose the disorder as early as possible in order to facilitate early therapeutic intervention. A child who has already been diagnosed with a specific disorder is treated as NDD. The movements of NDD children are less complex and monotonous. Their actions contain repetitive and stereotypical movements. Compared to TD and AR, NDD child's movement acceleration is very low. In summary, variations in motor skills are the best predictors to identify the developmental disorder during early infancy.

VII. FUTURE DIRECTIONS

After careful deliberations based on recent literature, some of the most promising future directions are outlined below.

- *Reduced complexity and increased computational power:* The wearability and affordability of sensing instruments eliminate the complexity of using expensive equipment such as video camera systems to record the mobility data. However, it is still required to minimize the complexity involved in handling wearable devices, especially for newborn babies and toddlers. Future devices should be so tiny as not to create any discomfort for the babies. For example, if a monitoring device is designed as a thin patch that can be attached to a child's clothing or socks, it would be even more comfortable than existing sensor devices. Hence, it is essential to consider the design of sensor devices for babies and toddlers while increasing their computational power.
- *Long-term Data collection:* Most of the studies conducted by the researchers have focused on the assessment of the data recorded over a short duration. The majority of the studies collected mobility data for 8 to 13 hours (Table 2) and occasionally some researchers have monitored the data for 2 to 7 days. Nevertheless, a few hours of mobility data are not sufficient for accurate decision-making. Moreover, the likelihood of results being biased towards a particular day would be higher in the case of short-duration data collection. For example, a child may be more active some days than others. therefore, to reduce such a bias, it is essential to include data over an extended duration. In addition to this, treatment progress monitoring is another crucial factor in intervention therapy. Therapy may continue for days and sometimes even for months. Thus, it is important to design sensing equipment in such a way that it can collect mobility data for an extended period without human intervention.
- *Extended battery life:* All wearable sensors indeed operate on minimal battery life. But, in the event of long-term data collection, it is not optimal to remove the device frequently to recharge it. This frequent change would add unnecessary noise to the data and often disturbs the child. Therefore, sensors designed for infants should be able to withstand a long duration without charging.
- *Sophisticated techniques to eliminate the noise:* The mobility data collected from infants consists of a huge amount of noise due to the infant's daily routine. Soothing a crying child, feeding, and diapering are some of the common and repetitive tasks performed by either patients or caregivers. Since these tasks appear more frequently in the collected dataset, they generate enormous noise. State-of-the-art noise processing methodologies are human-driven, and they must be carefully removed by programmers. The presence of noise in the dataset may produce either biased or incorrect results. Hence, there is an immediate need for sophisticated automated methods to detect and suppress noise in mobility data collected from children.

VIII. CONCLUSION

Developmental disorders such as autism, hinder a child's typical behavior. As a result, they do not grow up like a normal child. Thus, it is crucial to diagnose and start treatment as early as possible in early childhood. However, the most frequently used clinical methods are subjective and based on the judgment of an observer. Furthermore, infants are required to visit the laboratories frequently. Therefore, observer dependency makes the decision ineffective in the early detection of the disorder. Quantitative measurement of disability using smart wearable devices accelerates the diagnosing process. Wearable devices are sophisticated for monitoring the mobility data of infants. Quantitative methods using wearable sensors facilitate objective measurement of the disability. Wearable instruments are tiny, affordable, and suitable for kids to record mobility data unobtrusively. Quantitative diagnosis can be performed by collecting mobility data from children. This paper highlights the importance of mobility-based quantitative prognosis and presented the various diagnostic approaches that are explored by the scientific community as a method of identifying the disorder by employing sensor devices. In addition, it explains various mobility parameters that have been explored by the researchers while developing the techniques to identify the developmental disorder. Finally, promising research directions on which future research should focus were also presented.

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