Zarządzanie Przedsiębiorstwem. Enterprise Management
Volume 23 • Number 3 • September 2020 • pp. 2–9
DOI: 10.25961/ent.manag.23.03.01

MODEL OF THE ADAPTIVE DYNAMIC WORKPLACE

Blanka Horvathova, Luboslav Dulina, Eleonora Bigosova

University of Zilina, Faculty of Mechanical Engineering, Department of Industrial Engineering, Slovak Republic

Corresponding author:
Luboslav Dulina
University of Zilina
Faculty of Mechanical Engineering
Department of Industrial Engineering
Univerzitna 8215/1, 010 26 Zilina, Slovak Republic
phone: (+421) 415132722
e-mail: luboslav.dulina@fstroj.uniza.sk

Abstract
The hidden effect of the gradual transformation of work activities and, at the same time, the optimization of movements to increase the efficiency of the production system is the increase of the static component of work. However, the current setting of the legislative and ergonomic assessment does not sufficiently take into account the aspect of static load. Because the number of sedentary professions is continually growing and current office workplaces do not meet all ergonomic requirements, the presented model of an adaptive dynamic workplace is a possible solution to reduce the impact of static load and its consequences to the human body.

Keywords
Ergonomics, sedentary professions, office workplace, adaptability of workplace, controlled dynamics of sitting.

1. Sitting as a working position

No clear conclusions can be drawn from the survey of available studies in the field of sitting research and its impact on the human body. The scientific conclusion about which form of sitting is most suitable for a person is still not comprehensive. The only finding that unites scientists is the fact that long-term sitting is harmful to humans and has many adverse consequences [1].

The paradigm that the most suitable position for working in a sitting position is upright sitting cannot be considered universally valid in the context of available studies. Some studies report the 130° angle as the most suitable lumbar angle while sitting [1, 2].

The results of several analyses of ergonomic chairs indicate the fact that none of the commercially available chairs meets all the design parameters necessary to reduce the effect of static load during the performance of a sedentary profession [2].

Under specific conditions, sitting on a static chair proved to be more advantageous than sitting on a dynamic chair. However, the position of the spine and its parts is affected by many factors. The analysis pointed out to a serious fact – the extent of the movement of the chair joint on the monitored dynamic chair caused an unnatural and at the same time unacceptable position of the body. To ensure the correct dynamics of the seat, it is therefore necessary to limit the freedom of movement of the seat joint and at the same time monitor the working position of the employee to avoid improper working positions not only on the dynamic chair [2, 7].

Theoretical knowledge and findings from the analysis can be summarized in several points, which also characterize the current state of the issue:

- the number of sedentary jobs is still growing;
- sitting has a long-term negative overall impact on the human body;
- epidemiological studies show an increased incidence of diseases caused by long-term sitting and a physically inactive lifestyle;
- ergonomic chairs do not meet most of the parameters needed to ensure sitting ergonomics;
- ergonomic chairs do not ensure enough adjustment to the worker;
- the equipment of office workplaces is insufficient – the implementation of an ergonomic chair alone does not ensure the reduction of static load. To reduce the static load, it is necessary to equip workplaces with a complete system – an adjustable table and chair;
- the use of a dynamic chair alone for sedentary professions is not appropriate;
- the use of a purely static chair for sedentary professions is also not appropriate;
- dynamics of seating must be controlled and managed with minimal worker influence;
- to ensure the healthy performance of the sedentary profession, it is necessary to optimize all the structural elements of the office workplace – a table and a chair;
- the worker himself does not know how to properly harmonize himself, the table, the chair, and the work system. It is necessary to perform regular training

and inspection for the correct setting of individual elements of the workplace for an employee.

2. Design of an adaptive dynamic workplace model

The model of an adaptive dynamic workplace (ADW) consists of two technological parts: the construction of the workplace and the control system of the workplace. The basic structural units of an ADW are a height-adjustable table and a dynamic chair. The basic structure of the ADW is shown in Fig. 1.

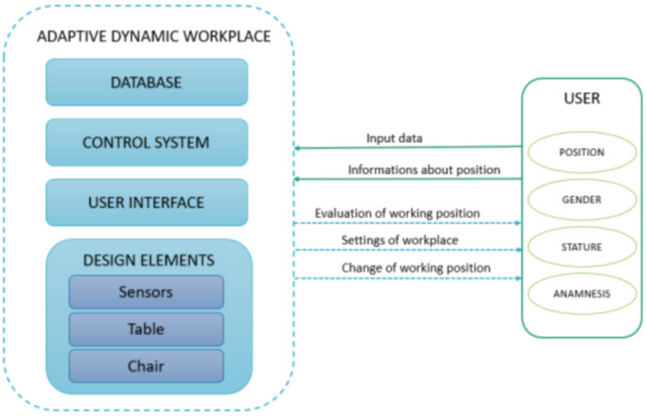

Fig. 1. The structure of the ADW [authors].

The adaptability of a workplace which involves sitting means the adaptation of the workplace to the anatomical and physiological requirements of the worker. Adaptability is ensured through the precise adjustment of structural elements to meet the specific physical requirements of an employee.

Workplace dynamics is represented by a dynamic change in working position. A change in working position is necessary to reduce the effect of static load on the body. The change of working position occurs independently of the worker's will. It means that the worker is forced to change the working position based on the evaluation of the system to ensure the necessary muscle relaxation.

2.1. Characteristics of an adaptive dynamic workplace model

In the first step, the ADW, immediately after sitting down on the chair, finds out in what natural working position the worker is. Subsequently, the employee enters into the system information about his height and gender, based on which the workplace in the first phase adapts its height to the worker. The system also detects the presence of signs of spinal deformity. If such a sign appears, the worker is asked to enter his diagnosis. If the worker is not aware of his spinal deformity, the system continues to evaluate the data with this identified condition.

The second step is to determine the correctness of the setting of the structural units of the workplace (table, chair). This detection is based on the collection of data from pressure sensors located in the upholstery of the chair and their subsequent comparison with the database.

Subsequently, the system evaluates in which of the recurring cycles (within in the duration of the session) the position of the worker is. This data is compared with a database of positions and pressure intervals. This is followed by finding out how long the worker has been in this position, regardless of whether the position is correct or incorrect. Subsequently, the detected time is compared with the intervals in the database. Separately for correct and incorrect positions.

The next step is to decide if the position needs to be changed. This decision-making takes place constantly, as the individual structures of the human body are constantly moving. The system thus also considers the accumulated time in individual positions to avoid overloading from the excessive long-term unilateral load. The result is a regular alternation of dynamic sitting, static sitting, and a complete change of working position from sitting to standing. Even during the alternation of sitting dynamics, the system still evaluates the working position in order to avoid damage to muscle bundles or load on the intervertebral discs due to extreme fluctuations in position or due to the so-called comfortable sitting of the worker.

2.2. Design elements of the ADW model

The ADW consists of three basic structural parts – an adaptive dynamic chair, an adaptive dynamic table and sensors for data collection and control of working positions and time intervals.

To meet the requirement of maximum adaptability, it is necessary that the working chair and worktable meet the following conditions for mechanical components:

- seat height – providing enough range to adjust the seat height so that the shortest women as well as the tallest men can use the chair;
- dimensions of the seat area and its inclination - design of the seat area regarding high variability in weight and anthropometric parameters of workers while maintaining the basic inclination of the seat, which is 2–3° for sitting;
- seat depth adjustment – adjustment of the seat depth by sliding it under the backrest. By sliding the seat under the backrest, it is possible to effectively adjust the appropriate seat depth for each worker;
- curvature angle of the front of the seat – determination of the angle of curvature so that the front edge of the seat does not cause increased local pressure on the lower thighs and lower leg area;
- backrest inclination – variable inclination of the backrest with enough rigidity. Insufficient resistance of the backrest was noted for some types of chairs marked ergonomic, and the backrest did not provide proper support to the worker when the sit-

ting position was relaxed, causing the worker to get into an incorrect recline;

- adjusting the depth and height of the lumbar support – ensuring variability in depth, i.e. movement of the backrest in the horizontal direction, and height, i.e. vertical shift of the backrest are key to maintaining proper curvature of the spine and providing enough support to the worker;
- headrest – the presence of a headrest is optional. Available studies do not address the effect of the head restraint on the worker during sitting. However, the head restraint may cause a constant slight tilt of the head. This forward bend can be triggered by a psychological aspect, it means subjective perception of the presence of an object behind the head. For this reason, a headrest is undesirable in the ADW concept;
- armrests – height adjustment, rotation around the z-axis, displacement in the front-rear direction and the angle of curvature of the leading edges;
- stable console with self-braking wheels;
- range of freedom of movement of the dynamic seat – the range of motion must have its limitations to avoid unacceptable working positions;
- table height – sufficient range of table height adjustment depending on the height of the chair so that the table is at a suitable height when sitting and when standing;
- surface treatment and table edges – insufficient material processing carries a high risk of injury or health problems and at the same time acts on the feeling of discomfort when sitting, which can result in irritability and reduced performance of the worker.

Dynamic locking system – automatic locking of sitting dynamics is necessary for the transition to a static position and at the same time for the transition to a standing position. Injury may occur if the chair is not locked. An example of a possible solution for an automatic locking system is shown in Fig. 2.

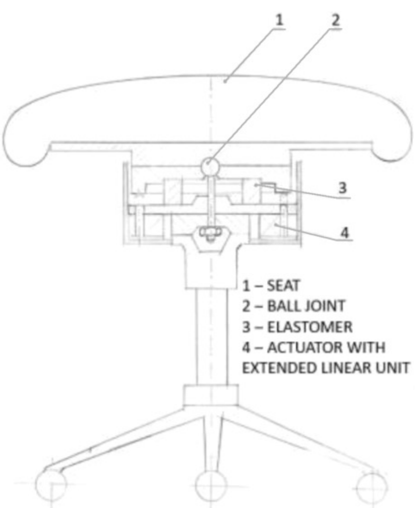

Fig. 2. Visualization of a possible design solution for automatic locking of the dynamic chair joint [authors].

Figure 2 shows the construction of the seat of the adaptive dynamic chair and the dynamic locking system. The seat is locked by at least three electric drives with linear retractable units with enough power to overcome the weight caused by the seated person. In the case of fitting with three locking pins, it is possible to regulate the inclination of the seat and ultimately compensate for any physical anomalies in the position of the spine. Under the seat, there is an elastomeric toroid that provides resistance to undue tilting from the horizontal axis of the seat. The ball joint provides partial spherical motion. An integrated battery must be considered in the design of the chair [4, 9].

Due to the constant technological progress and increasing the capacity of the batteries, it is possible to assume the supply of the necessary energy without the need for continuous charging during one shift.

2.3. Data collection using smart textiles

The collection of data needed to adjust the ADW and simultaneously to ensure controlled sitting dynamics and correct working positions is carried out by means of intelligent textiles - pressure sensors built into the seat and the backrest of the chair. The output data from these sensors can take the form of pressure maps (Fig. 3). The pressure maps of the individual positions are stored in the ADW database and subsequently compared and evaluated based on predefined reference intervals of values [6].

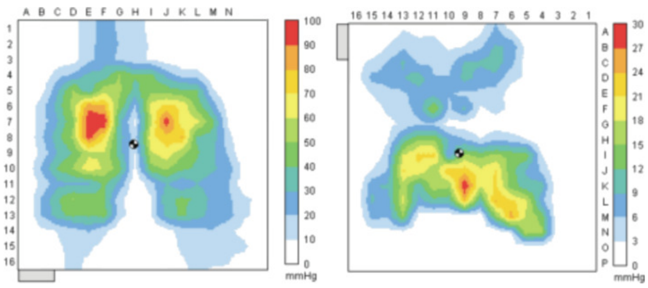

Fig. 3. Pressure maps – left pressure map from sensors on the chair seat, right: pressure map from sensors on the backrest [6].

The following table and chair parameters can be set via the pressure sensors built into the chair upholstery:

- seat height – insufficient or excessive pressure distribution in the thigh area;
- seat depth – the presence of knee pressure. Such a pressure distribution indicates that the seat is too long for the worker;
- lumbar support height – pressure distribution on the backrest;
- depth of lumbar support;
- height of the working plane – insufficient or excessive pressure on the backrest in the shoulders and elbows.

The setting of these parameters is possible only during a precisely defined basic sitting, which is a sitting during which the worker is resting on the backrest, his pelvis is as close as possible to the backrest, his feet resting on the ground and his hands resting freely on the desk. However, there may be situations when the chair or the table is set too high and the worker will not be able to rest his feet loosely on the ground. The appropriate setup is ensured by logging in with the user or entering input data on height and gender, where the ADW system compares this data with the database and then sets the workplace to the position recommended by the legislation for a worker with a given height.

2.4. Control system of adaptive dynamic workplace

The ADW control system cyclically monitors and evaluates the status of the connected devices, in which case these devices are a height-adjustable table, a working chair, pressure sensors and possibly also a camera system. The workplace control system is described by two types of diagrams. The first type is a state diagram and the second type is a flowchart.

The state diagram describes the individual states of the system into which it can enter, and the flowchart describes the development of the system, it means the sequence of individual events, commands, conditions, cycles or decision blocks.

The ADW control system can be terminated in any state by logging off the user. This means that after the user logs out of the system, the ADW becomes a normal office workplace [3, 5, 8].

2.5. State diagram of the adaptive dynamic workplace model

The state diagram of the ADW model describes the basic logic of the whole model. Each state has its own flowcharts.

The ADW is in free state when the system is activated. An employee login dialog is displayed on the computer screen. After the employee logs in, the status of the workplace changes to ADW occupied. In this state, the correctness of the measurement of the workplace sensors is checked, then the system goes into the ADW Initialization state. During the initialization of the ADW, the individual elements of the workplace are set based on the entered input data about the worker and based on the evaluation of the data from the pressure sensors. If the logged employee exists in the system database, the status of Workplace settings is continued. In case of unsuccessful initialization of the workplace, the status will change to Log off employee. In this state, the system logs off the worker and changes the state to ADW free (Fig. 4).

When initialization is OK, the ADW status changes to Workplace Settings. After verifying the correct settings of the system and all its components, the system goes into the Static Chair (S) state. In this state, the worker sits on a chair and the system cyclically evaluates the data needed to ensure the ergonomics of the sitting. It alerts the worker to change the seating position as needed.

When the time limit for sitting on a static chair is exceeded, the system changes the state to Dynamic chair (D). Even in this state, the system evaluates the data needed for ergonomics. After exceeding the time limit on the dynamic chair, the system switches back to the Static chair (S) state. This cyclic change between static and dynamic chairs continues until the time limit for changing the ADW state to the Standing Work state has elapsed. The worker is prompted to stand up and the system changes state to Work Standing. In this state, the timeout is also monitored. After this, the worker is asked to sit down, and the system changes the state to Static chair (S) (Fig. 5).

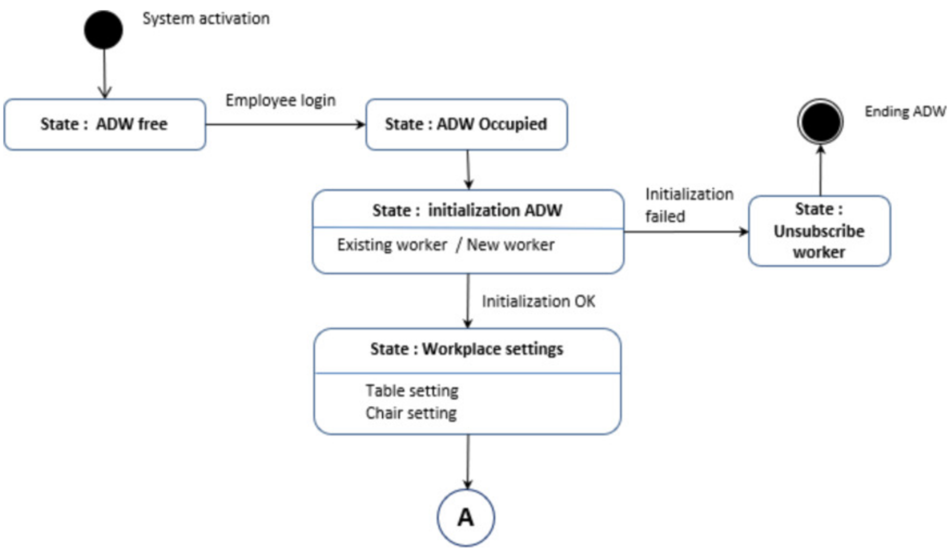

Fig. 4. The state of the ADW model – first part [authors].

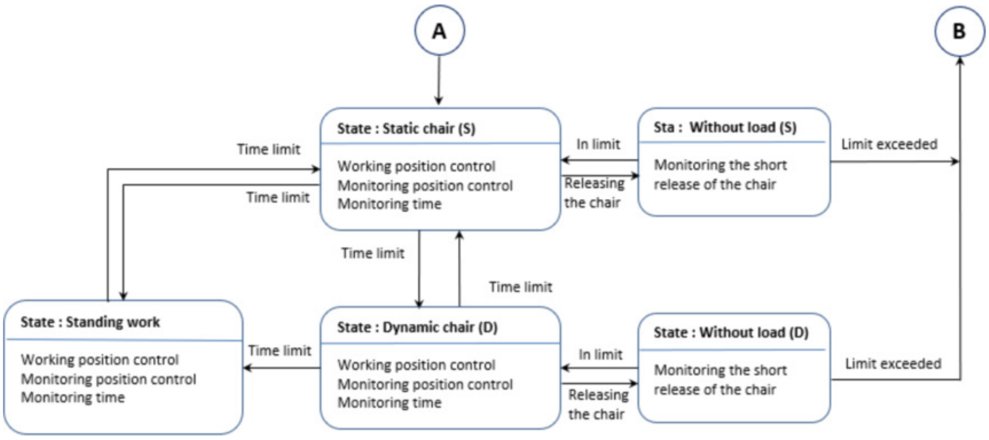

Fig. 5. The state diagram of ADW model – second part [authors].

With a static and dynamic chair, the system monitors whether the chair has become free. Releasing the chair is a situation where the worker gets up from the chair. In this case, the system sets the state No load (S or D). If the chair is released for too long and the set limits have been exceeded, the system sets the Log Off Worker status. If the worker sits down again within the time limit, the system changes the state back to Static chair (S). However, the workplace log off setting is optional, so it depends on the specific ADW implementation and the organization's input requirements. From the point of view of ergonomics and evaluation of the worker's seating patterns, it is desirable to leave the workplace in a state without load, but without logging off the worker. The situation when the ADW is in a no-load state is considered acceptable from the point of view of the influence of the static load and can be said to be desirable.

The employee terminates the work by logging out of the system. The parallel process the employee has logged off sets the ADW status to free, and the system is ready for the employee to log on again. Parallel system processes monitor the worker's logout - Worker logged out, and system failures - Process Mechanics failure. Another parallel process monitors whether the worker cooperates with the system – the Non-cooperating worker. Parallel process Data collection and statistics writes data to the system database and evaluates statistical data (Fig. 6).

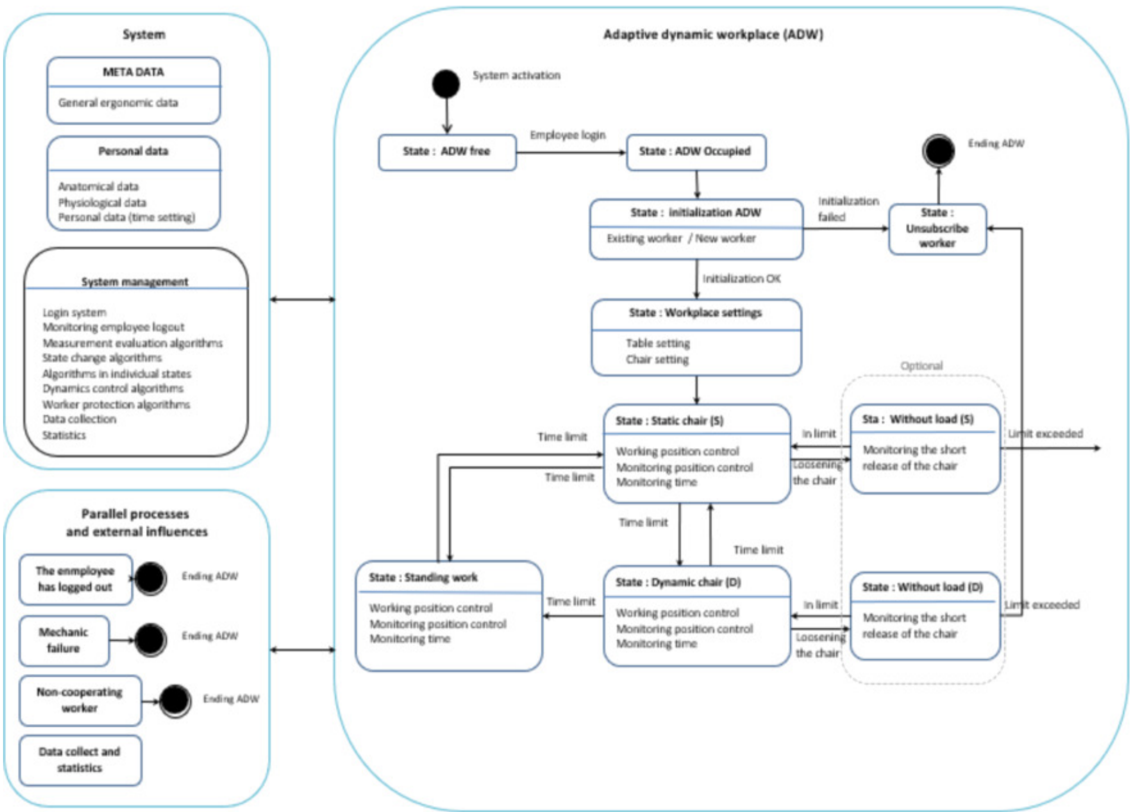

Fig. 6. The state diagram of the ADW model – parallel processes [authors].

2.6. Flowcharts of the adaptive dynamic workplace model – in general

A general flowchart for describing each condition is shown in Fig. 7. This diagram represents the basic construction of all flowcharts for individual states of the ADW model.

The basic process of evaluating states starts with a timer. The timer function is started periodically, and this period can be changed depending on the specific implementation requirements of the ADW. In the function of the timer, it is also possible to evaluate the conditions of parallel activities, such as the employee's logout, the occurrence of a failure or the evaluation of the employee's non-cooperation.

In the section Measurement of values and time, all measurements necessary for monitoring the worker and all measurements for monitoring the workplace are performed. At the same time, the current time for evaluating the limits is determined. In this block it is also possible to process the collection of measured data.

In the block Evaluation of conditions for state change, the conditions of the given state and transition to the next state are evaluated, such as employee login, initialization success, time limit for transition to another working position, etc. Based on the evaluation of the conditions, the status change flag is set.

Decision block "Change status?" is used to test for a change of a state symptom. After testing the status change, the blocks "Setting the status according to the fulfilled condition" and "Setting the status limits" follow. In these blocks, a new state is set, which means:

- limits and parameters are loaded from the database;
- workplace adjustments will be made – table, chair, other – required in the new condition;
- the alert text may change if an unexpected situation occurs while changing status;
- the alert text is set if necessary;
- the alert flag is set.

If in some states it is necessary to check whether the workplace is still set up correctly, this check is performed in the section Evaluation of state settings. Next, tests follow to determine whether it is necessary to adjust the settings for a given state in the OK state settings block? Based on the evaluation of this test, the command to modify the status setting follows in the Modify status setting block.

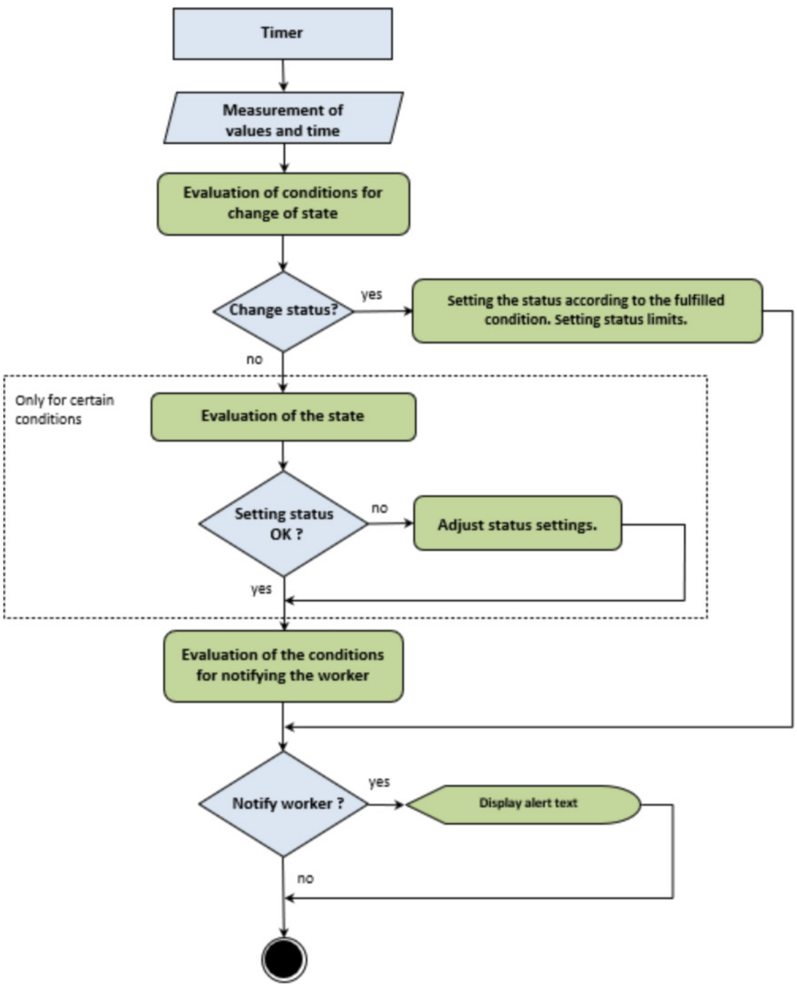

Fig. 7. Flowchart for a general description of each state [authors].

Table 1
Data files for the ADW database and their sources [authors].

Data file	File description	File data sources
Working positions	A data set designed to evaluate the individual work positions which the worker assumes.	Decree Min. health. SR no. 542/2007, ISO 11226: 2000, OWAS, RULA, database of pressure maps of working positions
Duration of working position	Two types of work position intervals - intervals for acceptable working positions and intervals for unacceptable working positions.	OWAS, Decree Min. health. SR no. 542/2007, ISO 11226: 2000, intervals for pressure sensors
Frequency of movements	Monitoring the frequency of movements in individual working positions with respect to the elimination of CTD.	RULA, Decree Min. health. SR no. 542/2007, intervals for pressure sensors
Table height	The values for setting the table height for sitting work and for standing work are different for men and women.	Decree Min. healthy SR no. 542/2007, Regulation of the Government of the Slovak Republic no. 276/2006, intervals for backrest pressure sensors.
Chair height	Values for adjusting the height of the chair for sitting work.	Decree Min. healthy SR no. 542/2007, Regulation of the Government of the Slovak Republic no. 276/2006, ISO 24496: 2017, intervals for chair seat pressure sensors
Seat depth	Value intervals for setting the seat depth.	ISO 24496: 2017, chair seat pressure sensors
Lumbar support height	Value intervals for adjusting the height of the lumbar support.	ISO 24496: 2017, backrest pressure sensors
Depth of lumbar support	Value intervals for adjusting the depth of the lumbar support.	ISO 24496: 2017, database of measurements by the DIERS system, pressure sensors of the backrest
Intervals for changing the working position	Limit values for remaining in the basic working position sitting or standing	Intervals defined by medical and ergonomic studies

This is followed by the block Execution of the workplace adjustment according to the check in the evaluation. In this block of the diagram, the conditions for notifying the worker are evaluated, and at the same time the data is processed and evaluated from the point of view of ergonomics from the measured values. If necessary, the information to be displayed to the employee is processed. If there is such information, a display flag is set. The next step is to test this display flag – "Notify employee?", Followed by a command to notify the employee. After the diagram ends, the system waits for the next start from the timer.

2.7. Database of adaptive dynamic workplace model

The control system of the ADW constantly evaluates the data obtained during its operation by comparison with the data stored in the database. The ADW database is based on valid legislation, standards, and ergonomic principles for the following areas:
- static load;
- dynamic load;
- dimensions of the workplace;
- working with display units.

The database further includes pressure reference intervals from the pressure sensors on the chair seat and the backrest. The individual data sets and their sources are summarized in Table 1.

3. Conclusion

This model of ADW contributes to the much-discussed issue of long-term sitting, and like any other model of this type, has its advantages, disadvantages, or limitations. The model of an ADW is designed based on a synthesis of available studies in the field of sitting, currently valid legislation and standards, current trends, own experience and research and critical procedures. A prototype of the model has not yet been created, so it was not possible to test it in real conditions. The prerequisite for this is the construction of a technical solution from currently available components.

This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-16-0488.

References

[1] Andersson G.B., *Epidemiological features of chronic low-back pain*, Lancet, 354, 581–585, 1999.

[2] Berlin C., Adams C., *Production ergonomics: designing work systems to support optimal human performance*, Ubility Press London, 127–138, April 2017.

[3] Bučková, M., Krajčovič M., Plinta D., *Use of dynamic simulation in warehouse designing*, ISPEM 2018, 835, 485–498, 2018.

[4] De Carvalho D., *Spine biomechanics of prolonged sitting: Exploring the effect chair features, walking breaks and spine maniputalion have on posture and percieved pain in men and women*, Doctoral disertation thesis in Kinesiology, Canada, 2015.

[5] Dodok T., Čuboňová N., Więcek D., *Optimization of machining processes preparation with usage of strategy manager*, Innovative Technologies in Engineering Production (ITEP 2018), 244 (2018), EDP science, 2018.

[6] Fujimaki G., Mitsuya R., *Study of the seated posture for VDT work*, Displays, Elsevier Science, Amsterdam, 17–24, 2002.

[7] Gabajová G. et al., *Virtual training application by use of augmented and virtual reality under university technology enhanced learning in Slovakia*, Sustainability, 11, 23, 6677, 2019.

[8] Katalóg profesií, https://www.pozicie.sk/.

[9] Plinta D., Krajčovič M., *Production system designing with use of digital factory and augmented reality technologies*, ICA 2015: Progress in Automation, Robotics and Measuring Techniques. Advances in Intelligent Systems and Computing, Springer, Switzerland, 350, 187–196, 2015.