A SYSTEM DYNAMICS APPROACH OF THE TEMPORARY WORK DISABILITY PRODUCED BY MUSCULOSKELETAL DISORDERS

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Abstract: Musculoskeletal disorders (MSD) are one of the most frequent causes of temporary work disability (TWD), accounting for productivity losses equivalent to 1.3% of the Gross National Product. The implementation of specific clinical programs can reduce the duration of MSD-TWD episodes and the number of patients going to permanent disability (PD) in a highly cost-effective manner. In this paper the MS-TWD episodes has been modelled and analysed using system dynamics techniques in order to explain how the medical intervention can get its objectives. The results confirm that the dynamic model developed is a useful tool to study in depth the disability due to MS diseases.

Keywords: Biomedical systems, dynamic systems, modelling, parameter estimation.

1. INTRODUCTION

The musculoskeletal disorders (MSD) have a great impact on individuals and society because of their high prevalence, morbidity and disability potential, and the large use of acute and long-term health care and support resources. Different studies (Yelin and Felts, 1990; Yelin and Callahan, 1995) have shown that MSD represent one of the most frequent causes of temporary work disability (TWD) and the first cause of permanent disability (PD) producing an important socio-sanitary cost to modern societies.

Health economic studies are now an essential part of health care evaluation (Lajas et al., 2003), and there are results (Abásolo et al., 2004) showing that a specific care program run by rheumatologists (return-to-work program) can reduce the duration of MSD-TWD episodes and the number of patients going to PD. Prevention of disability is emerging as a new health outcome with important socioeconomic consequences, above all in musculoskeletal diseases.

Disability is a complex and dynamic status that can be described as a system of a few interrelated factors changing in time and that have an effect on each other. System dynamics (SD) has proved to be particularly powerful for analysing why social, economic, ecological and other managed systems do not always behave as we wish them to (Coyle 1996) (Aracil and Gordillo, 1997). SD has been employed in Medicine to simulate the different behaviours (epidemic, endemic and pandemic) of the infectious diseases using the dynamic models proposed in Anderson and Nokes (2002). However, the SD has not been used yet to study the problems produced by musculoskeletal diseases.

In this paper the SD is used to model and to analyse the results of a previous randomized prospective interventional study (Abásolo et al., 2004). In comparison with the statistical techniques, normally used in medical research, the SD techniques consider important the temporal information and allow go deeply into the problem.

Section 2 summarizes the return-to-work program results. Section 3 is dedicated to explore two dynamic approaches of the TWD process. In both cases, the hydraulic analogy is discussed in order to explain how the medical intervention can improve the dynamic characteristics of the TWD process. From the good results obtained with the dynamic model follows the conclusions of section 4.

2. THE RETURN-TO-WORK PROGRAM

Ninety eight percent of the 5.5 million population of Madrid area receives health coverage from the Madrid's Institute of Health (IMSALUD). Medical care is organized in 11 health districts. Patients have direct access to Primary Care Physicians (PCP), who can refer patients to Specialized Care if necessary. All workers who discontinue their work for a health problem receive a TWD initiation form, which entitles them to obtain compensation payments. PCPs start and renew weekly the TWD forms until the worker either recovers, reaches a maximum of 18 months in TWD, or receives a proposal for PD. PD proposals are evaluated by the National Institute for Social Security (INSS), a division of the Ministry of Labour, which determines the need for and type of long-term compensation.

The return to work program (Abásolo et al., 2004) started in March 1998 in health district 7 and in March 1999 in districts nine and four of Madrid. The aim of the study was to evaluate the effect of a specific clinical intervention compared to the standard care on the outcome of patients from the general working population with recent onset MSD-TWD. Inclusion and randomization of patients took place during the first year of the study. Patients' follow-up was prolonged for another complete year avoiding crosses of patients between the groups in successive TWD episodes. Thus, the minimum follow-up period of any given patient was one year.

All patients diagnosed with new onset neither traumatic nor surgical MS-TWD episodes were randomized into two groups: Control (CG), following standard management, and Intervention (IG), enrolled in the specific program run by rheumatologists. All analyses were performed on an intention-to-treat- basis. A total of 13077 patients (7805 in CG and 5272 in IG), representing 3% of the working population, suffered 16297 MS-TWD episodes (9651 in CG and 6646 in IG), see Table 1. In IG, the TWD episodes were shorter than in CG (25.6 days versus 41.3; $p<0.001$ by log rank test). The intervention obtained a relative efficacy of 38% (the percentage of TWD days saved per episode in the intervention group respect to the control group).

Table 1: Results of the return-to-work program

	Control	Intervention
Total number of TWD episodes	9651	6646
Total number of days of TWD	398935	169912
Mean duration of episodes (days)	41.3	25.6
Relative efficacy of the program (%)		38

The temporal evolution of MSD-TWD episodes in each study group was registered in respective Kaplan Meier survival curves, see Figure 1. Each curve shows the percentage of TWD episodes still unfinished during one year period. Most episodes (89% in CG and 94% in IG) finished with return to work within first two months. Patients returning to work after six months (2.5% in CG and 0.7% in IG) were unusual, with many of them being off work for the complete 18 months period allowed by the administration. The smaller area under the IG survival curve illustrates the efficacy of the return-to-work program: the patients included in the specific care program were able to return to work earlier than patients under standard care.

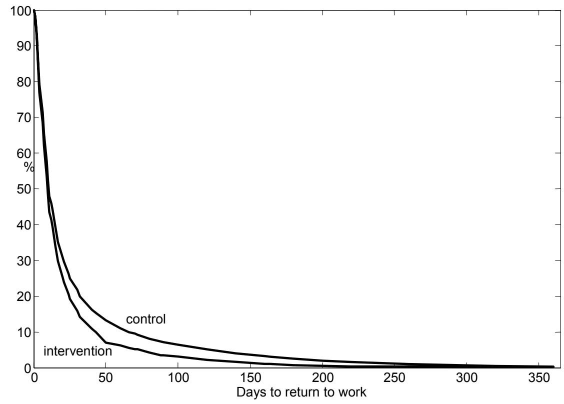

Fig. 1. Survival curves by group.

The program also demonstrated a positive effect in the percentage of patients achieving PD, measured four years after the finalization of the study, (data shown in Table 2; $p<0.001$). Fewer patients in the intervention group entering in the PD-evaluation process and receiving any form of long-term disability compensation or early retirement.

Table 2: Permanent Disability (PD) by group: n (%)

	Control	Intervention
Patients proposed for PD	187	71
PD proposal accepted	114 (61.0)	44 (62.0)
PD proposal rejected	73 (39.0)	27 (38.0)

3. THE SYSTEM DYNAMICS APROACH

The system dynamics approach of the MS-TWD episodes assumes that the TWD process is a continuous process, where there are always flows of patients returning to work or going to PD.

3.1 The elemental approach.

Looking the Figure 1 it is easy to select a mathematical function which can fit the survival curves. This function can be the exponential (1) because: it takes the value 100 at t=0, becomes zero when t becomes ∞ and it is monotonous decreasing.

$$y(t) = 100\, e^{-\frac{t}{\tau}} \qquad (1)$$

The expression (1) is solution of the diferential equation (2) when y(0)=100. Therefore, it has a very simple hydraulic analogy; y(t) is the instant level of a tank that was full (100%) of liquid and finished empty (0%) because the tank has a valve and the outflow rate of liquid through the valve has been proportional to the level of the tank. This is the basic principle of any negative feedback.

$$\frac{d\, y(t)}{dt} = -\frac{1}{\tau}\, y(t) \qquad (2)$$

Though the dimensions of the tank and the size of the valve have an effect on this proportionality, opening more or less the valve it is possible to accelerate or to break the emptying of the tank. Using this hydraulic analogy for the TWD process, the effect of the medical intervention would correspond with the manipulation of the valve. And the only parameter τ of the function (1), the time constant, would mean the average duration of the TWD processes

The Figures 2 and 3 show the original data and the two exponentials that better approximate the survival curves. The time constants of these functions are respectively 29.5 and 20.6 days, and have been obtained to include the same area (A = 100 τ) that the respective survival curve.

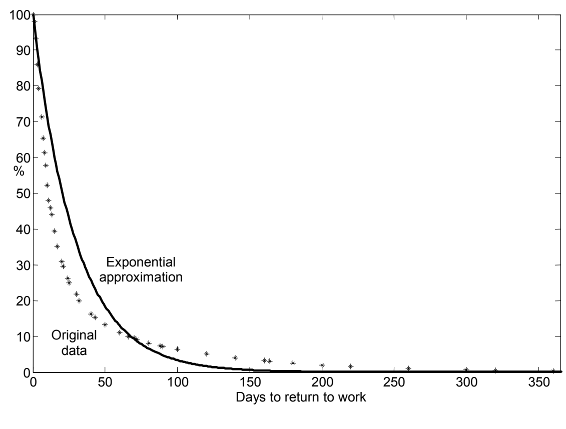

Fig. 2. Exponential approximation of the survival curve in control group.

The functions are no quite close to the survival curves because these do not have a perfect exponential shape. The number of patients in TWD decreases very fast the first days but later it decreases slowly, being this difference more marked in the control group. Therefore, it is possible to conclude that the TWD processes are more complex; their dynamics cannot be described by the first order differential equation (2) nor can be characterized by a single time constant. This conclusion confirms also the experience of the medical team. They think that there are two types of behaviours between the patients in TWD, most patients (about 90%) return to work quickly (in less of 2 months), but the remainder return slowly or finish being off work.

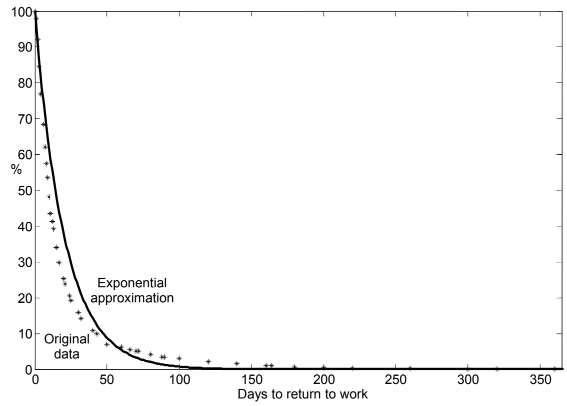

Fig. 3. Exponential approximation of the survival curve in intervention group.

3.2 The hydraulic analogy.

Based on the conclusion of section 3.1, on the characteristics of the TWD described in section 2, on the experience of the medical team and also on our system dynamics knowledge, the hydraulic analogy of Figure 4 is proposed for the TWD process. In this model, composed of five tanks and six valves, it has been considered that:

- There are two types of TWD patients, short-term patients (tank 1) and long-term patients (tank 2), that return to work (tank 3) after a short period of time (through the valve 1) or a long period of time (through the valve 3).
- The patients starting a TWD episode are always considered as short-term patients (SWD), but some of them will reach later the consideration of long-term patients (LWD) (through the valve 2).
- Some long-term patients never return to work, because after a period, waiting for PD evaluation (tank 4), they get it (tank 5). The remainder do not get the PD and must return to work.
- The medical intervention can improve the dynamic characteristics of the system in several ways:
  - Opening the valve 1: this is equivalent to reduce the average duration of patients in SWD.
  - Closing the valve 2: this reduces the percentage of patients in SWD that will reach the consideration of LWD.

- Opening the valve 3: this reduces the average duration of the patients in LWD.
- Closing the valve 4: this reduces the percentage of patients in LWD that apply for PD.
- Opening the valve 5 and closing its complementary (valve 6): this increases the percentage of patients that will get the PD because they were well diagnosed.

3.3 The dynamic model.

Based on the hydraulic analogy of Figure 4 is almost immediate to formulate a mathematical model for the TWD with the following equations, where are used the variables of Table 3:

$$\frac{d\,PSWD(t)}{dt} = PSTWD(t) - PFSWD(t) - PS2LWD(t) \quad (3)$$

$$PFSWD(t) = \frac{PSWD(t)}{ADSWD} \quad (4)$$

$$PS2LWD(t) = \begin{cases} 0 & \text{if } t < ADSWD \\ \frac{PPS2L}{100} PSWD(t) & \text{if } t \geq ADSWD \end{cases} \quad (5)$$

$$\frac{d\,PLWD(t)}{dt} = PS2LWD(t) - PFLWD(t) - PAPD(t) \quad (6)$$

$$PFLWD(t) = \frac{PLWD(t)}{ADLWD} \quad (7)$$

$$PAPD(t) = \frac{PPAPD}{100} PLWD(t) \quad (8)$$

$$\frac{d\,PWPD(t)}{dt} = PAPD(t) - PGPD(t) - PNGPD(t) \quad (9)$$

$$PGPD(t) = \frac{(100 - PUPD)}{100} \frac{PWPD(t)}{AWTPD} \quad (10)$$

$$PNGPD(t) = \frac{PUPD}{100} \frac{PWPD(t)}{AWTPD} \quad (11)$$

$$\frac{d\,PRW(t)}{dt} = PFSWD(t) + PFLWD(t) + PNGPD(t) \quad (12)$$

$$\frac{d\,PPD(t)}{dt} = PGPD(t) \quad (13)$$

$$PFTWD(t) = PFSWD(t) + PFLWD(t) \quad (14)$$

$$PTWD(t) = PSWD(t) + PLWD(t) \quad (15)$$

The differential equations (3), (6), (9), (12) and (13) establish the mass balance in each one of the five tanks, so they described how change the number of patients in the five different states. The algebraic equations (4) and (7) express the outflow of short-term and long-term WD patients using the concept of average duration of the process as they were isolated processes. The relations (8), (10) and (11) summarised how a percentage of the long-term WD patients apply for permanent disability, but their

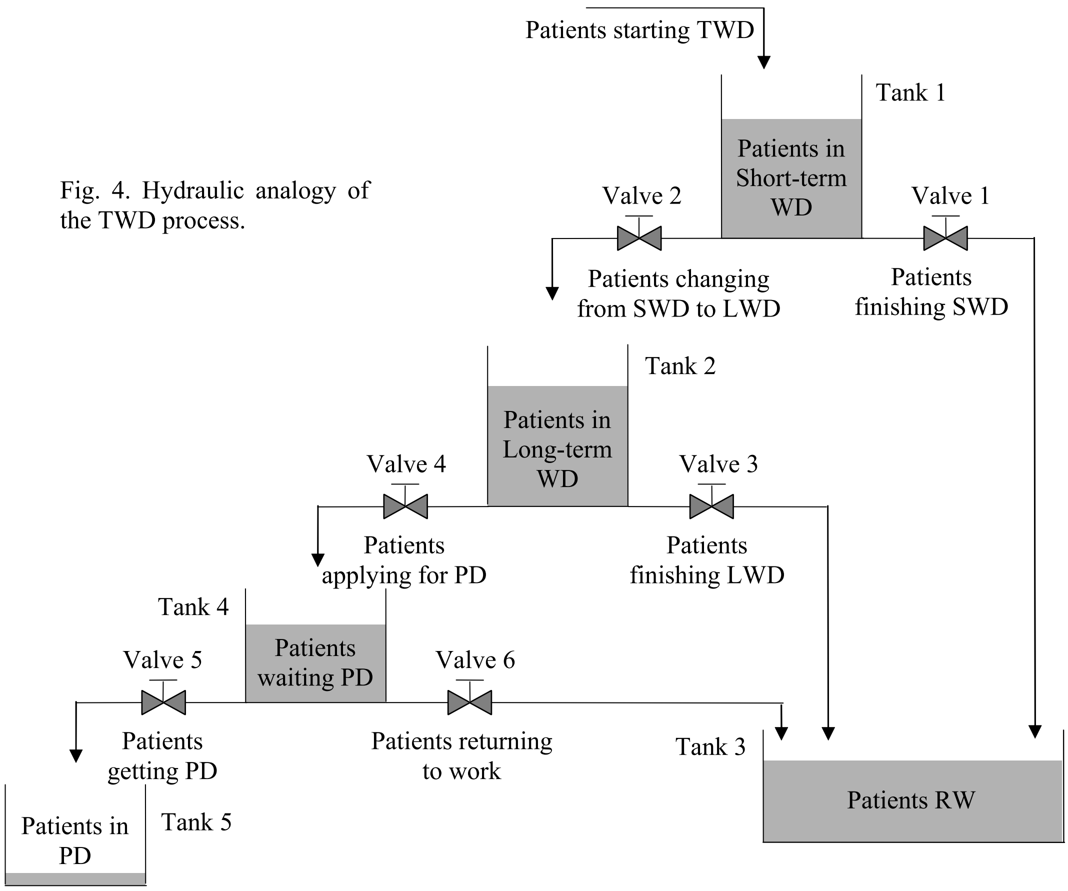

Fig. 4. Hydraulic analogy of the TWD process.

evaluation is not immediate and there is not total security of get it. Equations (14) and (15) have been used in order to make accounting and to reproduce the survival curve within the mathematical model.

Table 3: Variables of the model

Name	Type	Meaning
PSWD	Level	Patients in Short-term Work Disability
PLWD	Level	Patients in Long-term Work Disability
PWPD	Level	Patients Waiting for the Permanent Disability evaluation
PRW	Level	Patients that have Returned to Work after a short-term or long-term work disability or after wait without success the permanent disability evaluation
PPD	Level	Patients that have got the Permanent Disability after a long-term working disability and wait with success the evaluation
PSTWD	Rate	Patients/day that Start a Temporary Work Disability
PFSWD	Rate	Patients/day that Finish their Short-term Work Disability
PFLWD	Rate	Patients/day that Finish their Long-term Work Disability
PS2LWD	rate	Patients/day that change from Short-term to Long-term Work Disability
PAPD	rate	Patients/day that Apply for Permanent Disability and therefore have lost the consideration of patients in long-term work disability
PGPD	rate	Patients/day that Get the Permanent Disability
PNGPD	rate	Patients/day that do Not Get the Permanent Disability
PFTW	auxiliary	Total number of Patients/day that Finish their Temporary Work Disability
PTWD	auxiliary	Total number of Patients in Temporary Work Disability
ADSWD	parameter	Average Duration of the Short-term Work Disability
ADLWD	parameter	Average Duration of the Long-term Work Disability
PPS2L	parameter	Percentage of Patients/day that were considered in Short-term work disability and in the future will be considered in Long-term disability
AWTPD	parameter	Average Waiting Time for the Permanent Disability evaluation
PPAPD	parameter	Percentage of Patients/day in long-term work disability that Apply for Permanent Disability
PUPD	parameter	Percentage of Unfavourable Permanent Disability evaluations

The expression (5) deserves a special attention because this is the only non-linearity included in the model; it is needed to prevent that short-term WD patients can reach the consideration of long-term at the beginning of the simulation. The average duration of the short-term WD has been chosen as the elapsed time to the short-term WD patients can change of status.

3.4 Tuning the model parameters.

The dynamic model proposed in section 3.3 has six parameters, tuning these parameters it is possible to reproduce the survival curves of Figure 1. In order to tune the six parameters, it is possible to use different strategies and all of them involve an optimization process. For example, the dynamic model could be used to make intensive simulations until the TWD results were quite close to the corresponding survival curve. However, it is preferable to solve the equations in order to have an explicit temporal expression of the TWD patients.

The survival curve is the solution of the equations when: PSTWD(t)=0 $\forall$t, PSWD(0)=PTWD(0), PLWD(0)=0, PWPD(0)=0, PRW(0)=0 and PPD(0)=0. That is to say, all the patients have started their temporary work disability in t=0 and there are not new incorporations in the future.

Until t<ADSWD, the patients in short-term WD (tank 1 of Figure 4) only outflow to tank 3, returning to work. The solution in this time interval is given by

$$\mathrm{PTWD}(t) = \mathrm{PTWD}(0)\, e^{-\frac{t}{\mathrm{ADSWD}}} \qquad (16)$$

In t=ADSWD the patients begin to flow to the other two tanks. Then, the equations can been solve with the new initial conditions PSWD(ADSWD) = e^{-1} PTWD(0), PLWD(0)=0, PWPD(0)=0, PRW(0) = (1-e^{-1}) PTWD(0). The solution in this time interval is given by

$$\mathrm{PTWD}(t) = e^{-1}\,\mathrm{PTWD}(0)\, e^{-\frac{t-\mathrm{ADSWD}}{\tau_1}} + \frac{\mathrm{PPS2L}}{100}\, e^{-1}\,\mathrm{PTWD}(0)\,\frac{\tau_1\,\tau_2}{\tau_1-\tau_2}\left(e^{-\frac{t-\mathrm{ADSWD}}{\tau_1}} - e^{-\frac{t-\mathrm{ADSWD}}{\tau_2}}\right) \qquad (17)$$

where

$$\tau_1 = \frac{1}{\frac{1}{\mathrm{ADSWD}}+\frac{\mathrm{PPS2L}}{100}} \quad \tau_2 = \frac{1}{\frac{1}{\mathrm{ADLWD}}+\frac{\mathrm{PPAPD}}{100}} \qquad (18)$$

In the explicit temporal expression of the TWD patients given by (16), (17) and (18) appear only four parameters (ADSWD, ADLWD, PPS2L and PPAPD) of the model. The other two parameters (AWTPD and PUPD) do not affect the shape of the survival curve, however they affect the evolution of the variables PRW(t) and PPD(t) and its final values PRW(∞) and PPD(∞). How all initial patients PTWD(0) will finish returning to work except those who get the permanent disability, the following relation is obtained from the dynamic model:

$$\frac{\mathrm{PPD}(\infty)}{\mathrm{PTWD}(0)} = \frac{100-\mathrm{PUPD}}{100}\,\frac{\mathrm{PPAPD}}{100}\,\frac{\mathrm{PPS2L}}{100}\,\tau_1\,\tau_2\,e^{-1} \qquad (19)$$

It is needed to use this additional relation to tune the model parameters because there are several set of the four parameters that give good approximation of survival curves but not good values of PPD(∞) and PRW(∞). The relation (19) is known because the value of “PPD(∞)=number of PD proposal accepted” is in Table 2. Moreover, the parameter PUPD can be calculated from the data of Table 2 as “100 by number of PD proposal rejected/number of patients proposed for PD".

The Figures 5 and 6 show the original data and the best survival curve approximation by the dynamic model in each group. These good results confirm that the dynamic model proposed in section 3.3 and its hydraulic analogy in Figure 4 are an excellent approach to the TWD process. Looking at the four tuned parameters in both groups, see Table 4, it is possible explain how the specific medical intervention affected the TWD process in the return-to-work program:

- The average duration of the short and long-term work disability is two days (14 versus 16) and eighteen days (57 versus 75) lesser in IG than in CG. The intervention was effective in short-term episodes as well as in long-term ones.
- A twice percentage of patients/day (7 versus 3.5) in CG change from short-term to long-term WD comparing with IG. The intervention reduced the number of patients chronically disabled.
- The intervention did not affect the percentage of patients/day applying for PD (0.17 versus 0.15).

Table 4: The four tuned parameters by group

	Control	Intervention
ADSWD	16.34	14.27
ADLWD	75.18	56.88
PPS2L	6.95	3.47
PPAPD	0.15	0.17

4. CONCLUSIONS

The system dynamics approach to the temporary work disability allows to explain how the medical team affects the TWD process and can improve its dynamic characteristics; decreasing the average duration of short or long-term work disability episodes, decreasing the percentage of patients that get the permanent disability and increasing the percentage of patients that return to work.

The excellent approximation of the survival curves in control and intervention groups have allowed validating the dynamic model. The medical team can use this model and its parameters to study in depth the disability due to musculoskeletal diseases, to evaluate the cost of their decisions and to explore the best scenario for future interventions.

ACKNOWLEDGEMENTS

This study was carried out with a grant of the National Ministry of Health (FIS number PI020893).

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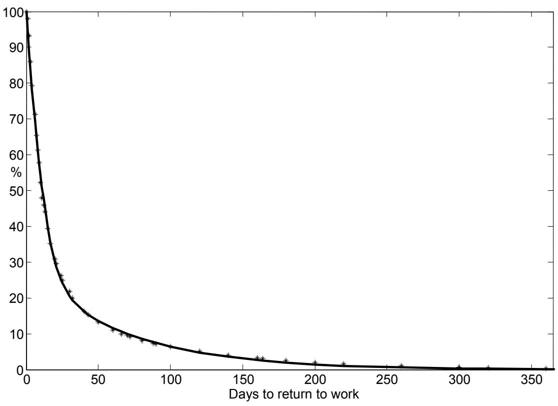

Fig. 5. Approximation of the control group survival curve by the dynamic model.

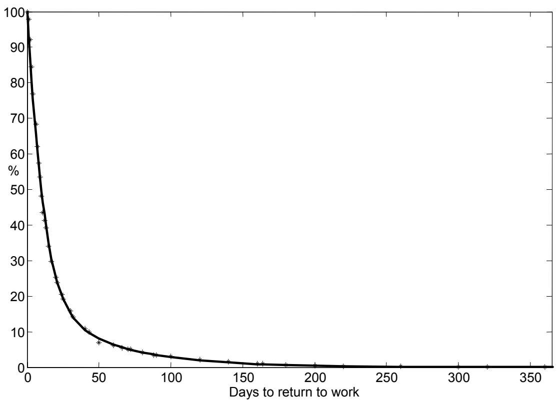

Fig. 6. Approximation of the intervention group survival curve by the dynamic model.