**Diary Studies as a Macro-Ergonomic Evaluation Tool:
Development of a Shift Diary and its Application in Ergonomic Evaluations**

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Diary Studies as a Macro-Ergonomic Evaluation Tool

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Abstract — A diary instrument that could be used as a macro-ergonomic evaluation tool was developed and applied to evaluating monitoring tasks. In the first part of the study, the development of the instrument allowing the measurement of employee evaluations of workload, attained performance, and strain is presented. Railway signalers and controllers filled out a diary every four hours over ten consecutive working shifts. Analysis of the objective workload conditions of the railway signalers and their relations to subjective workload perceptions in the diary indicates a satisfying validity of the measures. In the second part of the study, the newly developed diary instrument was used for macro-ergonomic evaluations in two other controller work places. Using the shift diary it was possible to answer practical macro-ergonomic questions that originated from the respective work situations. The strengths and possible limitations of the diary instrument are discussed.

Diary study; job analysis; macro-ergonomics; monitoring task; shift work

I. INTRODUCTION

Employee reactions that are of interest in ergonomic theory and research often vary considerably over the course of a working day or a working week. Perceptions of workload and strain, for instance, display daily and weekly temporal dynamics due to changing work demands [1,2]. Likewise, attentiveness and vigilance in monitoring tasks vary over the course of a work shift, as does fatigue [3,4]. Conventional self-reporting methods, often applied in macro-ergonomic and organizational research, disregard such short-term variations within a person and focus primarily on differences between people or on long-term changes. Diary methods, however, offer the opportunity to collect fluctuating data over time and to investigate temporal dynamics. They allow researchers to “capture momentary behaviors and psychological states in context” and to “track those behaviors and states over time” [5: 440].

In diary studies, employees answer frequent questions about the events and experiences of their daily (work) lives. Diary methods are therefore also referred to as “momentary ecological assessment” [5]. Depending on the study, two general types of diary studies may be distinguished [5,6,7]: time-based designs and event-based designs. In diary studies using a time-based design, people are asked to provide data at fixed or random time intervals. Assessment times may, for example, be scheduled at specific times of the day (e.g., 9am, 1pm, 5pm) or at specific time intervals (every four hours), or may follow a

random pattern unknown to the participants. A prerequisite for applying this type of diary method is the frequent occurrence of the phenomenon under study. When analyzing rare behaviors or experiences, such as work conflicts, the time-based assessment is not appropriate; such phenomena should rather be investigated using the event-based design [6]. In this case, study participants are requested to provide information and fill in a diary every time a predefined event occurs. For example, participants would have to report every work-related conflict, be it with co-workers, supervisors or customers.

Both types of diary study offer specific advantages for use in ergonomic research [7]. Firstly, time-based and event-based diary studies offer the opportunity of gathering data in the context of employees’ normal life. Instead of collecting data in an experimental setting, diary studies allow researchers to “capture life as it is lived” [6] and to take the situational context into account when studying work behavior [7]. They therefore provide ecologically more valid information on work-related processes. Secondly, both designs aim to keep recall biases to a minimum by reducing the time elapsing between the occurrence of an event and its assessment. In event-based designs participants should report relevant behaviors and experiences as soon as they occur. In time-based designs, participants are requested to indicate their feelings and thoughts at a particular moment, or to describe their workload during the preceding hours.

In addition to these advantages, time-based designs are also especially suitable for investigating temporal dynamics and assessing relations between fluctuating states, experiences, or behaviors [7]. Using time-based diary studies, ergonomists may answer research questions such as: Do vigilance and fatigue change over the course of a working day or a working week? Do such changes follow a linear or a cyclical form? Diaries even offer the opportunity of combining daily or hourly reports with objective measures of changing work demands or with physiological measures, in order to study the antecedents and consequences of work-related stress. Although traditional longitudinal designs also involve repeated assessments, they typically span larger time intervals and contain fewer measurement points. They therefore capture short-term changes less precisely than diaries.

Given the power of diary studies to assess short-term fluctuations, they constitute an important tool for analyzing the effects of shift work on workers’ fatigue and recovery, and for

investigating and explaining changing levels of vigilance and attentiveness during monitoring tasks. As all these phenomena are likely to vary over a working day, time-based diary methods enable ergonomists to detect critical points and to design control systems that help employees to stay vigilant and to thereby foster safety.

The aim of the current study is the development of a shift diary and its application in two further macro-ergonomic evaluation studies at controller work places. The practical advantages of such a time-based diary approach in the three organizational settings are discussed.

II. THE DEVELOPMENT OF A SHIFT DIARY

As part of a research project that focused on the effects of recovery and workload on strain in railway signallers and controllers, we developed a shift diary. The research project targeted signallers and controllers working at a fully computerized railway control center in Central Europe. From the control center, signallers and controllers monitor and control rail traffic in an area of approximately 12,500 km² around the clock in twelve-hour shifts.

The aim of the development of the shift diary was to create an instrument allowing workload as well as other job demands and job resources to be assessed as unobtrusively as possible. Additionally, the shift diary should enable the measurement of fatigue and other forms of strain reactions during the job, and of recovery during off-job time.

A. Selection of relevant constructs for the shift diary

In shift work – and especially in shift rosters based on twelve-hour shifts – the question arises whether recovery between shifts is sufficient. We therefore decided to include items measuring recovery and psychological detachment from work during leisure time based on previous research by Sonnentag and her colleagues [1,8,9].

To identify relevant job demands and job resources for inclusion in the shift diary, we analyzed job descriptions provided by the management of the control center and reviewed literature on signallers and controllers [e.g., 10,11,12,13]. In addition, we conducted semi-structured observational interviews based on the instrument for stress-related job analysis of computer work [14]. Twelve signallers and twelve controllers working at the aforementioned control center took part in these interviews.

Based on the literature review and the interviews, we decided to include five job demands (core task workload, administrative demand, multitasking demand, time pressure, and underload) and two job resources (time control and situational awareness) in the shift diary. The core task workload consists of the demands on employees related to monitoring the rail infrastructure and intervening directly, as well as communicating with colleagues to coordinate plans for interventions [cf. 12].

In the observational interviews the signallers and controllers unanimously reported particularly high workloads when construction work was taking place in their observation sector or when critical events occurred (e.g., technical malfunctions or incidents causing injury to people). We therefore decided to

also collect data about the presence of construction works and the occurrence of critical events in the shift diary.

As outcome measures we included items on performance, namely efficiency and safety, similar to the Taskload-Efficiency-Safety-Buffer Triangle [15]. Another group of outcome measures was related to strain, namely effort and frustration, which were adapted from the NASA Task Load Index [16,17]. The final group of outcome variables consisted of measures of well-being, including positive affect, negative affect, fatigue and experienced monotony.

B. Procedure, sampling intervals, and selection of scales and items

Although we could have designed a web-based diary study as computer systems with internet access were available to the signallers and controllers, we decided to refrain from using a computer-supported approach for implementing the shift diary. The user input was continuously logged by the system and we wanted to avoid concerns about the anonymity of the responses. Thus we decided to implement the shift diary as a conventional paper-and-pencil diary study [6], which also allowed the participants to carry their personal shift diary with them or put it into their personal lockers at the control center.

The shift diary resembled a time-based diary study [6] with four diary entries per shift and fixed intervals of four hours between entries. We expected this timeframe to be small enough to enable the signallers and controllers to report the intensity of job demands and job resources without dramatic memory biases. At shift onset we collected data on recovery during the previous break period as well as on well-being. With the remaining three diary entries in each of the twelve-hour shifts (four, eight and twelve hours after shift onset) we assessed the intensity of job demands and job resources as well as the outcome variables. In the last diary entry per shift we asked about construction works and the occurrence of critical events throughout the whole shift, which made the shift diary partly event-based [6].

Each diary entry was started by filling out the current date and time at the top of the diary sheet. Next we assessed positive affect, negative affect, fatigue, and experienced monotony using single-item scales based on previous studies [18]. In each diary entry, participants indicated on 6-point rating scale (1 = not at all, and 6 = a lot) whether they felt that they were “in a good temper”, “tired”, “annoyed”, or “bored”.

At shift onset we assessed recovery during the previous break period using a three-item short scale originally developed to measure the antipode of recovery, *need for recovery*, in diary studies [9]. Using a 5-point rating scale (1 = not at all true, and 5 = utterly true) participants indicated whether: (a) “During the time off I would have needed more time for relaxing and recovering from work” (recoded); (b) “Considering the total of all activities that I pursued during my time off, I have had enough time to relax and to recover from work today”; and (c) “All things considered I was able to recover sufficiently during the time off” (Cronbach’s $\alpha = 0.89$). Psychological detachment was also measured at shift onset by a three-item scale, which was adapted from Sonnentag and Bayer [1]. Using the same 5-point rating scale as for recovery (1 = not at all true, and 5 =

utterly true), participants indicated whether: (a) “During my time off I forgot completely about my working day”; (b) “During my time off I could ‘switch off’ completely”; and (c) “During my time off I had to think about my work again and again” (recoded) (Cronbach’s $\alpha = 0.86$).

Job demands and job resources were measured four, eight, and twelve hours after shift onset. Participants rated the perceived intensity of each job demand and job resource during the preceding four hours on a 7-point rating scale (1 = very low, and 7 = very high). All job demands and job resources except the core task workload were assessed using single-item measures. Core task workload was assessed using three items (workload related to monitoring, intervening, and communicating): Cronbach’s α s were 0.89 after four hours, 0.91 after eight hours, and 0.92 after twelve hours of shift work. Efficiency and safety as well as effort and frustration were assessed using a single item on the same 7-point scale as the intensity of job demands and job resources. All items were self-constructed and consisted of a short and bold title that was elaborated by a short description directly below in a smaller font. The layout was inspired by the NASA Task Load Index [16,17] (cf. figure 1).

Please indicate the intensity of the following aspects during the past third of your current shift:	very low 1	2	3	4	5	6	very high 7
monitoring demand monitoring train movements, classification yards and construction works	☐	☐	☐	☐	☐	☐	☐
intervening demand active interventions through the system	☐	☐	☐	☐	☐	☐	☐
communicating demand radio and telephone communication as well as emails	☐	☐	☐	☐	☐	☐	☐
administrative demand reading of norms, handling instructions and working rules	☐	☐	☐	☐	☐	☐	☐
multitasking demand switching back and forth between multiple tasks	☐	☐	☐	☐	☐	☐	☐
time pressure rate of speed at which tasks occur	☐	☐	☐	☐	☐	☐	☐
underload stress due to insufficient tasks; it is hard to stay attentive	☐	☐	☐	☐	☐	☐	☐
time control dealing with tasks and taking breaks when you want to	☐	☐	☐	☐	☐	☐	☐
information and overview sufficient information; awareness of the situation in your sector	☐	☐	☐	☐	☐	☐	☐
attained quality high quality = timeliness (little additional accrued delays)	☐	☐	☐	☐	☐	☐	☐
attained security security that you could assure	☐	☐	☐	☐	☐	☐	☐
effort experienced effort while achieving the performance	☐	☐	☐	☐	☐	☐	☐
frustration experienced negative emotions during that time period	☐	☐	☐	☐	☐	☐	☐

Figure 1. Overview of the self-constructed scales and items for job demands, job resources, performance, and strain.

On the diary sheet for the last entry per shift (twelve hours after shift onset), we included items indicating whether there were construction works in the monitored sector and whether critical events had occurred during the twelve-hour shift.

As the tasks of signalers and controllers tasks require them to continually monitor their train sectors and be aware of the current situation, it was necessary for the single diary sheets to be filled out quickly and require as little cognitive load as possible [3]. We therefore decided to use single-item scales to assess most of the relevant constructs. This reduced the time required to fill out each diary sheet to approximately two or three minutes, or about ten minutes in total per shift.

Despite the importance of reducing the cognitive load of participants when completing the diary entries, we decided to use different rating scales with different anchors for some of

our constructs. The reason for this was that we wanted to reduce potential common method variance based on common scale formats or common scale anchors [19].

C. Results with respect to the validity of the shift diary

Although it is not possible to calculate the reliability of most of the dimensions, we observed satisfactory results with respect to criterion validity and predictive validity.

Over six weeks in April and May 2010 we collected data from a sample of sixty-four participants out of a total of seventy-one signalers and controllers working at the control center (return rate: 90%). The shift diaries were handed over to each participant individually and this was followed by short semi-structured face-to-face instructions. All respondents were male. As compared with the general working population, the average age of participants ($M = 47.1$ years, $SD = 4.9$) and the average job tenure ($M = 26.5$ years, $SD = 6.7$) were relatively high. Sixty of the sixty-four participants provided complete diary entries over ten consecutive shifts, with the remaining four participants filling out at least four consecutive shifts, resulting in a total of 626 diary data sets available for analysis.

In addition to the data collected in the shift diary, we were able to collect objective workload data from the computer logs at the control center. The logs included the overall number of train movements during each shift in the region monitored as well as three indicators of interventions by the signalers (number of interventions in the regular train traffic, number of interventions in the classification yards, and number of critical interventions that require documentation). These data were matched with the diary data provided by signalers.

By calculating the average core task workload for each workstation per shift (averaging diary entries four, eight, and twelve hours after shift onset), we calculated an index of *core task workload* during the whole shift. We expected this index of core task workload to be related to the objective demands. Therefore the index should be predicted by the objective data from the control center’s computer systems.

Using multiple regression analysis we found that the four objective workload indicators together accounted for 26% of total variance of the calculated index of core task workload, $F(4, 275) = 23.98, p < 0.001$. This is quite high, since common method variance can be ruled out [19,20]. The most relevant predictor, with a standardized regression coefficient of $\beta = 0.31$ ($p < 0.001$), was the number of interventions in the classification yards, while the other three objective indicators had a smaller influence on core task workload (with β s ranging from 0.15 to 0.21, all $ps < 0.01$). Similar results were found when we included multitasking demands and time pressure in the index of demands, but not when we included administrative demands or underload. These latter demands appear to co-vary less closely with core task workload over time. Overall, the results indicate a good criterion validity of the shift diary’s core task workload scale.

It was also shown that the shift diary had good predictive validity: Analyses using hierarchical linear modeling showed that high recovery and high psychological detachment from work during the previous break period reduced the effect of workload during the shift on fatigue at the end of the shift [21].

III. APPLICATION OF THE SHIFT DIARY IN MACRO-ERGONOMIC EVALUATIONS

Although the shift diary was developed in the context of a research project in the first place, we soon discovered its potential for application as a macro-ergonomic evaluation tool for job evaluations at controller work places. The following two examples illustrate the use of the shift diary as an empirical macro-ergonomic approach aimed at work design improvements. In both studies we were able to use the diary to answer practical macro-ergonomic questions originating from the respective work situation.

A. Hydro-electric power plant control center

As part of an analysis of the working conditions at a hydro-electric power plant control center, we adapted the shift diary slightly. The short descriptions elaborating the individual items for job demands, job resources, and performance were adjusted to the specifics of the power plant control center, and the number of diary entries per shift was adapted to its shift roster. Within the analysis, the aim of the diary study was to answer the question whether and under what conditions working hours could be extended from eight to twelve hours during night shifts.

Using the shift diary, we collected data from six operators (return rate: 75%) working at a hydro-electric power plant control center in July 2010. The operators monitored and controlled multiple hydro-electric power plants cascaded along a river around the clock in eight-hour shifts. We were able to analyze data from a total of 56 working shifts. Because of the small sample size, we decided to run the analysis on the level of the individual diary entries.

During day shifts, the control center was staffed by two operators (except during weekends), whereas during night shifts the control center was staffed by a single operator. To answer the question of whether longer shifts would be acceptable, we decided to analyze (a) whether there were relevant differences within core task workload, effort, attained efficiency, and attained security between day and night shifts and (b) whether these differences were stable during (self-reported) critical events or not.

We therefore conducted 2x2 ANOVAs (shift type: day vs. night shift; critical event: yes/no) for core task workload, effort, attained efficiency, and attained security as dependent variables. Operators reported critical events in 31 out of 83 (37%) diary entries during day shifts and 6 out of 24 (25%) diary entries during night shifts.

As expected, *core task workload* was higher during day shifts than during night shifts, $F(1, 104) = 28.90, p < 0.001$, and it was also higher when critical events occurred, $F(1, 104) = 15.39, p < 0.001$. No significant interaction was observable with core task workload, $F(1, 104) = 1.74, p > 0.05$. The results for *effort* showed a similar pattern to those for core task workload, except that there was no difference in effort between day and night shifts, $F(1, 104) = 0.53, p > 0.05$. This might be due to the fact that the control center was staffed by two operators during the more work intensive day shifts. As expected, effort increased with critical events, $F(1, 104) = 31.21, p < 0.001$, and no significant interaction was observable with effort, $F(1, 104)$

$= 3.60, p > 0.05$. *Attained efficiency* was higher during day shifts as compared to night shifts, $F(1, 103) = 10.55, p < 0.01$, and lower during critical events as compared to time periods without critical events, $F(1, 103) = 11.35, p < 0.01$. There was also a significant interaction of shift type and critical events on attained efficiency, $F(1, 103) = 6.09, p < 0.05$, with particularly low attained efficiency during night shifts when there were critical events (cf. figure 2). *Attained security* showed a similar pattern as attained efficiency, with higher values being observed during day shifts as compared to night shifts, $F(1, 104) = 12.50, p < 0.001$, lower values during critical events than at other times, $F(1, 104) = 12.71, p < 0.001$, and a significant interaction, $F(1, 104) = 7.17, p < 0.01$. Again – almost identical to the results for attained efficiency – particularly low attained security was found during night shifts when there were critical events (cf. figure 3).

Figure 2. Interaction of shift type and critical events on attained efficiency.

Figure 3. Interaction of shift type and critical events on attained security.

The interaction effects of shift type and critical events on attained efficiency and attained security showed that the performance of power plant operators suffered when critical events occurred during night shifts. As a result of the analysis of the diary study, we advised the management of the hydro-electric power plant control center not to extend shift length during night shifts unless they implemented a stand-by duty that could be called on by operators if critical events occurred.

B. Car manufacturing plant control center

As part of another analysis focusing on the working conditions of two different control centers (electricity control; plant safety control) at a car manufacturing plant, we once again slightly adapted the shift diary to the specifics of the control

centers and employed it. In this study we aimed to answer the question of whether and under what conditions the two control centers could be merged into a single integrated control center.

Using the shift diary, we collected data from all six operators at the electricity control center and all four operators at the plant safety control center in December 2011 and January 2012 (return rates: 100%). The operators at the electricity control center worked on a shift roster consisting of eight- and twelve-hour shifts. Their main task was to ensure that the plant was permanently supplied with sufficient electric power for production (goal: 99.95% uninterrupted services) without wasting energy. The main tasks of the operators at the plant safety control center, working on twelve-hour shifts, were fire prevention, operational safety, and building surveillance. By extending the maximum number of protocolled shifts per participant to twenty, we were able to analyze data from 231 diary entries from 108 shifts of electricity control operators and 198 diary entries from 68 shifts of plant safety control operators.

One goal of the analysis was to identify areas where an improvement in current working conditions would be advisable. Another goal was to give empirically based recommendations for a pilot phase of the integrated control center. As part of the pilot phase, electricity control operators would be trained to handle the core tasks of the plant safety operators. Subsequently they would take over these tasks in addition to their tasks as electricity control operators.

With the use of the shift diary, we were able to demonstrate that in both control centers break periods between shifts should last for more than twelve hours. Recovery values of break periods of twelve hours or less were significantly lower than those of longer break periods for electricity control operators, $t(100) = 7.59, p < 0.001$, as well as for plant safety operators, $t(62) = 5.79, p < 0.001$ (cf. figure 4). As a consequence, we advised the management of the control centers to improve the shift rosters.

Figure 4. Recovery of operators by length of previous break period.

To obtain empirical based recommendations regarding the integration of the two control centers, we analyzed the course of job demands over an average working day separately for each control center (cf. figure 5). We observed that the pattern of job demands over time was similar in both control centers. As individual diary entries of corresponding time slots from the two control centers could be matched, we were able to compute the correlation of the core task workload of both work places,

$r(175) = 0.29, p < 0.001$. For an integration of both jobs, a zero correlation (or even a negative correlation) would have been preferable, as this would indicate that core task workload in both centers is not related over time. Because of the relatively high positive correlation (which is attributed to the fact that in some situations of system errors or system breakdowns both control centers are affected at the same time) and the observed time pattern of core task workloads with their highest values between 6am and 2pm, we decided to advise eliminating as many subsidiary tasks as possible, especially during the day. We also encouraged the management to consider having two controllers work side by side during the day and only integrate the control tasks of the two control centers during night shifts.

Figure 5. Time course of core task workload over an average day.

IV. DISCUSSION

In the first part of this study, we developed a diary method which allows empirically based ergonomic recommendations, with the goal of improving the working conditions of controller work places. In the second part of the study, the diary method was employed in two macro-ergonomic analyses. We were able to show that the diary approach offers the possibility of measuring workload and strain conditions over time and that ergonomic recommendations could be based on empirical time-related data.

The diary approach as developed in this study offers a number of advantages. First of all, when implementing a diary approach it is possible to track events, behaviors and states over time, which allows the continuous analysis of time-related phenomena, such as perceived workload, strain or fatigue. Diary studies are also an ecological approach. By using short scales or even single items, it is possible to track time-dependent perceptions over a work shift without the measurement itself intruding the perceptions of the employees. A wide range of monitoring tasks was investigated in the three portrayed diary studies. In all three controller work places, the diary instrument was highly accepted by the employees; because little time is required to fill out the diaries, it is possible to observe longer working periods (for instance, in the third study we observed twenty consecutive shifts, which was related to an continuous observation period of five or six weeks). The acceptance of the instrument by the employees is also reflected in the high return rates in all three cases. More im-

portantly, it was shown in all three examples that the diary measures are sensitive enough to capture even small workload differences in the controller work places. In addition, the subjective perceptions seem to mirror the “objective” workload conditions in the work places. Thus, the single-item measures in the diary were found to be sensitive and valid measures of workload conditions.

From a scientific perspective, a strong advantage of diary studies is the inherent possibility for analysis of cause-effect relationships. However, we suggest using this approach for ergonomic evaluations as part of a multi-source multi-method approach in combination with other ergonomic evaluation tools, like observations, interviews and work analysis.

Additionally, it needs to be mentioned that single-item measures may be problematic because of their limited reliability. In current diary-based research studies, short scales are often recommended [6,7]. However, we think that our study was able to show that for practical ergonomic evaluations single items may be a more parsimonious approach. Using objective workload criteria, the validity of the single-item measures was demonstrated.

The three diary studies served as examples of possible applications of diary studies for ergonomic evaluations. The role of recovery and psychological detachment during break periods in reducing the effects of workload during subsequent shifts on fatigue in the first study confirmed the importance of the quality of the break periods between the shifts. The second study revealed drops in attained efficiency and attained security during night shifts when critical events occurred in the plant control center. As a consequence, we advised extending shift length only if a stand-by duty was implemented. On the basis of the results of the third study, we were able to make empirically based recommendations regarding the integration of two controller work places into one combined work place.

The work places in the three studies presented examples of a wide range of monitoring tasks. In all three cases, shift work was executed. In these settings the diary approach showed their immanent strong advantages. A diary approach could also be used in macro-ergonomic evaluations in other working areas, for example for office and administration tasks.

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