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TIME BUDGET ANALYSIS AND RISK MANAGEMENT: ESTIMATING THE PROBABILITIES OF THE EVENT SCHEDULES OF AMERICAN ADULTS[1]

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ABSTRACT

Comprehensive risk management must account both for the exposure and consequences of risks. Time budget analysis focuses on the activities and location of people, which are directly related to potential exposure, and consequences of risk. The analysis of the distribution of daily activities allows risk analysts to adjust exposure likelihoods for the changing population distribution over the course of a 24 hour period. In addition, time budget analysis allows the risk analyst to account for shifts in potential consequences associated with location of people at various times of the day. This paper examines three significant aspects of time budget analysis and risk management. First, the direct exposure rates to ongoing hazards as a function of the amount of time spent at risk (e.g. in an automobile, or airplane, or outdoors in a neighborhood adjacent to an uncontrolled hazardous materials site). Second, the effect on the likelihood of exposure to and severity of consequences for relatively sudden events (e.g. toxic chemical spills, radioactive leaks, other airborne risks transmitted via the plume-exposure pathway, tornadoes, earthquakes and flash floods). Finally, the effect on risk management through effective emergency management is directly related to location and activity of people at various times of the day (e.g. likelihood of warning receipt, probable evacuation flow dynamics, and likelihood of inadvertent adaptive location).

KEY WORDS: Time Budget, Risk Management, Exposure, Consequences, Emergency Management

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INTRODUCTION

Risk management is concerned with the problem of describing the relation between a risk generating phenomenon and a human population. The characterization of this relation is particularly useful when it accounts for both space and time. Examples of temporally and spacially distributed hazards abound: Dangerous weather systems impact specific geographic locations during particular seasons of the year and times of the day. Nuclear power plants reside at specific locations, and power lines follow identifiable routes. This relation between a risk generating phenomenon and a human population can be conceptualized as several stochastic processes (Rowe 1977, Lowrance 1976, Shrader-Frechette 1985). One is concerned with the likelihood of a risk generating event, (eg. the likelihood of a tree falling in the forest). Another concerns whether, given such an event, it would impact the human population (eg. given that a tree falls, the likelihood that it would hit someone). And finally given the event and the impact, what is the distribution of consequences. This paper concerns the second set of probabilities and their estimation.

The approach used to estimate these probabilities is based on a simple idea; probabilities can be estimated from data on how and where people spend their time. For example, the probability of whether a person will be at home at 6:15 PM can be estimated from the time and activity logs that comprise the foundation of time use research. In fact, time budget analysis allows the risk analyst to describe the activity profile for the entire day in terms of the best point and interval probability estimates for an incredibly detailed range of activities. This paper highlights the use of time budget data in risk management.

Three Types of Uses are Highlighted:

1. Estimating direct exposure and dose rates due to ongoing hazards (eg. being outdoors in neighborhood adjacent to an uncontrolled hazardous materials site, being indoors subjected to "indoor pollution," or outdoors exposed to ultraviolet rays of the sun with its possibility of skin cancer).

2. Estimating exposure, dose and potential severity of relatively sudden hazardous events (eg. being located in an area subjected to a toxic chemical spill, being indoors when an earthquake or tornado occurs, being outdoors during a radiation leak at a nearby facility).

3. Estimating the likelihood of effective emergency management in terms of emergency planning and the dissemination of warning, potential for (other inadvertent) adaptive/maladaptive locations, and potential for adaptive response.

Time Budget Surveys

In 1975, the Survey Research Center at the University of Michigan administered a time budget survey to a national probability sample of U.S. households (Robinson 1977). The same households participated in a second panel of the same survey in 1981 (Juster et al, 1983). In the 1975 survey, 1519 households were surveyed, which included 1519 respondents and 887 spouses. In 1981, attrition in the panel reduced the sample sizes to 620 households, with 620 respondents, and 376 spouses. The 1981 survey added the time budgets of children in the households.

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A comparison of 1975 with 1981 results indicates that the attrition in sample sizes caused little, if any, bias in the results. Controlling for demographic variables indicates that the time budgets of U.S. households were amazingly stable over this period of time. The results in this study are from an analysis of the 1981 panel data.

For both the 1975 and 1981 surveys, four waves were administered, one during each season of the year. For each wave, respondents and spouses were asked to construct a one day (24 hour) log of his or her activities. The log describes the set of all activities the person engaged in during the previous day. Over the four waves of each survey, respondents reported on their activities for two weekdays, and two week end days. The 1975 survey contains 7207 person-days of data and the 1981 contains 3350 adult-days and 881 children-days.

Most of the published reports of these University of Michigan data are based on an aggregated "synthetic week" (Stafford and Duncan 1978 and 1980, Stafford 1980). The two weekdays and two weekend days are combined and weighted to estimate how Americans spend time over an annual average week. For many types of studies, such data are well suited. However, for risk analysis, the synthetic week approach does not provide enough detail about the daily schedules of people. Therefore, this analysis developed a different data structure better suited to risk analysis.

<u>The Period-Activity Data Structure</u>

The raw time log records contain, in part, the following items: respondent identification number, day of week, month, date of interview, activity code (ie., a typology of 233 detailed activities), time activity began, time activity ended, secondary activity code, and elapsed time for activity. Typically, about 30 records describe the activities for a respondent for each day. These raw data are processed in two ways to form a period-activity data structure.

The Michigan time budget activity codes cover 233 detailed activity types. The detail is illustrated in terms of a few examples. Activities in the home, such as meal preparation, are coded in terms of several categories, including meal preparation -- cooking, meal preparation -- clean-up, and meal preparation -- other. Travel activities are comprised of travel to and from work, in search of employment, to and from shopping and to and from day care facilities, to name but a few. Both primary activities, those dominating a particular period, and secondary activity, those being conducted in the background while other activities are undoubtedly conducted, use these detailed activity codes.[2] To use these time budget data in risk management, these detailed data are collapsed from 233 activity codes to 11 broader categories reflecting some major risk management situations. Specific risk applications are best treated in terms of their unique exposure-dose-consequence profiles and their associated time budget implications. The collapsed activity codes are: 1) at home--asleep, 2) at home--active, 3) at work, 4) watching TV, 5) listening to the radio, 6) at neighbor's home, 7) not home--indoors, 8) shopping for goods and services, 9) at home--outdoors, 10) not at home--outdoors, 11) in transit.

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2. A secondary activity is one that is engaged in at the same time as a primary activity. An example is listening to the radio (secondary) while eating dinner (primary).

These eleven categories[3] describe the kinds of places where people conduct their daily activities. They maintain the distinction of being home or away from home, being indoors or outdoors, and being active or asleep. Also, these broader categories of the daily activities are a mutually exclusive and exhaustive re-categorization of the 233 detailed codes. Interest concerning specific risks may not entail exhaustive categories, but for our purposes this seems most appropriate. Finally, because sleep time is both such a dominant activity in a person's time budget, and because it is a primary consideration risk management, it is maintained as a separate activity.

The second part of the raw record processing involves aggregating time spent in individual activities into composite activity time in the 11 categories during a period of the 24 hour day. Twelve two hour periods were used for this aggregation. Thus for each respondent in each wave, a data record was computed that described the number of minutes spent in the 11 category codes during each of 12 periods of the day. This means period-activity record contains 132 time use variables, plus other variables describing the day, the respondent, and household characteristics.

<u>Analysis of the Period Activity Data</u>

The most dominant feature of the average annual time budget is being at home asleep. Comprising 34.8 percent of an individual's total daily time on average, being home asleep is heavily concentrated in the midnight to 6am period, secondarily in the 6am to 8am and 10pm to 12 midnight periods. For the five two-hour periods beginning at 10pm, the average amount of time spent sleeping at home in each two-hour period is 50.3, 88.1, 94.4, 90.8 and 52.7 percent respectively. This seems to reflect a daily pattern of the typical household. In fact it is what one might expect, but the implication for risk management rests in the amount and sequence of the sleep activity.

The second most dominant feature of the annual time use budget is the time being active in the home. This primary activity comprises 23.9 percent of the typical day. Together, in-home active and asleep categories account for 58.8 percent of the total daily activity of adult Americans. The third most dominant daily activity is work. Working comprises another 11.1 percent of the average total time budget. Concentrated during day-light hours (ie. 8am to 5pm), at its peak periods work comprises 25.8 percent of the period between 10am and 12 noon. Taken jointly these three primary activities comprise 69.9 percent of an average person's daily routine. Figure 1 presents the annual average time use budget for all eleven primary activities.

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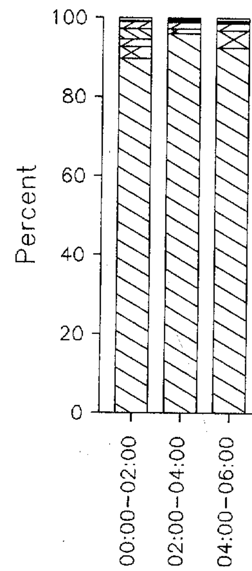

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While the remaining categories, taken jointly comprise 30.1 percent of the total time budget, separately none of the remaining categories account for more than 10 percent of a typical person's total time. Watching television accounts for the majority of the remaining time, at 8.1 percent. Compressed primarily within the 8pm to 10pm period, and secondarily within the two-hour period before and after prime-time viewing, watching TV is the forth most dominant daily activity. Considering almost all TV viewing is conducted in the home, all activities in the home comprise 66.9 percent of the daily budget. Adding the amount of activity conducted outdoors at home and in neighbor's home, 72.7 percent of the daily activity takes place in the residential neighborhood. This underscores the use of residential population data as the foundation for risk management issues concerning exposure, severity, consequences, and emergency mitigation. However, the more detailed time budget analysis builds more precise daily location/activity into the exposure/consequence quantification.

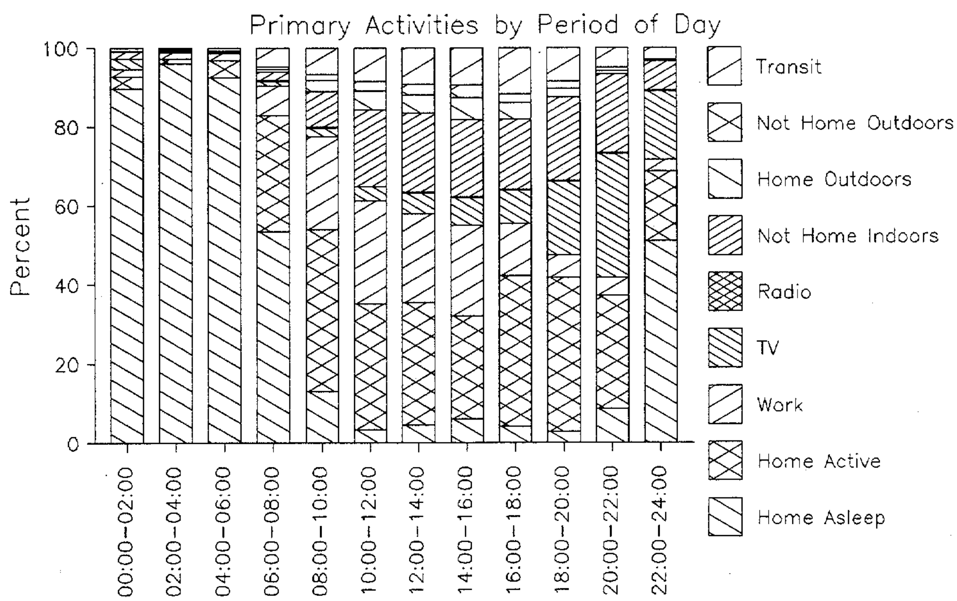

Figure 1

Annual Average Time Use Budget

Electronic media, including radio and television exposure, account for slightly more of the daily activity, however, when secondary media exposure is considered. The media "window" expands from 8.3 to 12.7 percent of the average daily time. This analysis suggests that nearly 13.0 percent of the average daily activity is exposed, either through primary or secondary activity to the electronic media of TV or radio. Figure 2 highlights the media exposure window which is critical in connection with emergency warning--alerting and notification. As a primary activity, radio provides very little warning potential, the maximum exposure as a primary activity is during the 6am to 8am period, and is only 0.3 percent. As a secondary activity, radio provides about a 4 percent exposure across the working hours of the day, with a peak of 4.8 percent in the 8 a.m. to 10 a.m. period. Radio listing falls off in the evening, when television, as a primary activity predominates. TV offers an 8.1 percent coverage as a primary activity, which increases to 10 percent when taken as a primary and secondary activity. During Day-light hours (ie. 8 a.m. to 6 p.m.) TV accounts for 2.4 percent of the primary activity. However, it provides 5.9 percent coverage during the same period as a primary and secondary activity.

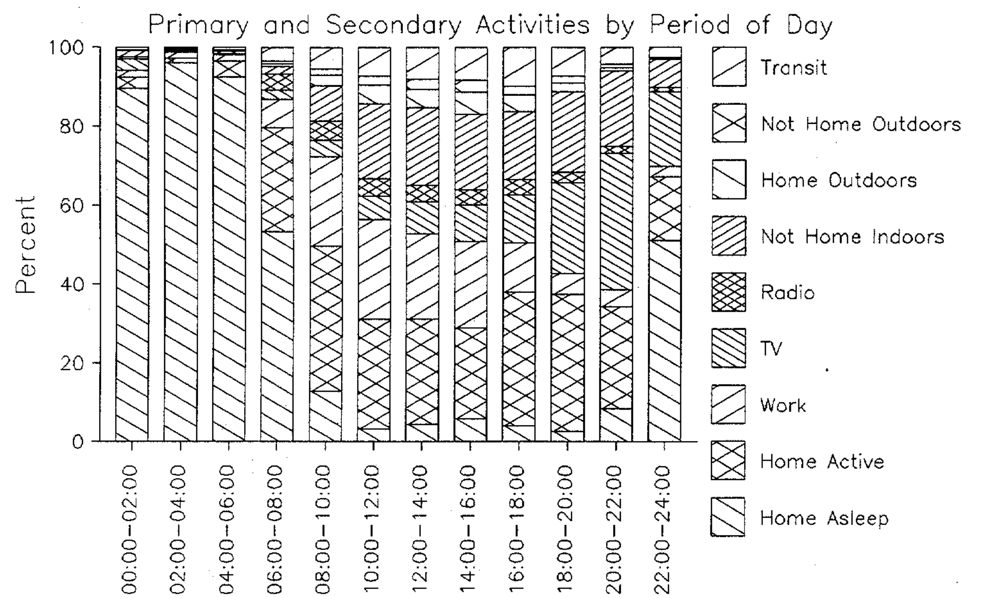

Figure 2

Annual Average Time Use Budget

Activity conducted away from home indoors accounts for 11.4 percent of the typical day. This activity is comprised of 3.7 percent in neighbor's home, 3.5 percent shopping and 4.2 percent in other indoor locations away from home. While shopping seems to be concentrated in the early afternoon periods, other indoor activities away from home seem to increase through the day-light hours, tapering off after 10pm.

Transportation activities comprise 5.6 percent of the average individual's day. Being in transit is concentrated in the day-light hours, steadily increasing from 6am, and reaching its maximum during the evening rush hour. Furthermore 15.4 percent of the time in transit is exposed to the electronic media, presumably the radio.

<u>Low-level Ongoing Hazards</u>

The use of time in specific places, within specific areas, undertaking particular activities is directly related to exposure to ongoing hazards. Because the average adult American spends so much time at home, the exposure within the home is fundamentally important. The World Health Organization task force suggested guidelines to control only a handful of the more common indoor pollutants. The suggested standards covered, formaldehyde, asbestos, carbon monoxide, carbon dioxide, nitrogen dioxide, and sulfur dioxide (Johnson 1983). Radon in homes accumulates from underground sources hidden from the occupants (Nero 1985), but arsenic is usually airborne (Albert 1985, Patrick and Peters 1985, Baird <u>et al</u> 1985). While the situation is often difficult in work environments, it is often no better at home (cf. Johnson, 1983, Raloff 1985, Hicks 1984). Often the detection of indoor pollution, which is frequently made worse by weather tight buildings, known as the "tight building syndrome," is complicated by relatively poor detection systems (Michaels 1984).

Working outdoors also has its problems. Construction and maintenance crews, farmers and ranchers and year-round workers in the frozen food industry must be concerned about the amount of time spent in the cold (Polakoff 1982). Exposure to ongoing hazards in individual settings may be estimated on the basis of time budget data. For example, an estimated 500,000 U.S. homes contain urea formaldehyde of varying concentrations (Johnson 1983). When divided by the 82.4 million households in the U. S. this represents a crude exposure rate of $6.07 * 10^{-2}$. But refining this estimate by the 66.9 percent of the time spent in the home yields an estimated exposure rate of $4.06 * 10^{-2}$. If we are only concerned with sleep or bedroom exposure, we might estimate the probability of exposure as a function of proportion of households and proportion of time at home asleep, yielding and exposure rate of $2.11 * 10^{-2}$. We can also be less concerned if we find a linkage between day light hours, and in-home pollutants (e.g., should we find that solar heat releases some noxious gas into the home). Because 44.6 percent of the period between 8am and 4pm being spent in the home, the refined exposure rate is $2.83 * 10^{-2}$. Furthermore such gas can dissipate prior to the concentrated exposure associated with evening and night-time occupation. The relatively basic time budget analysis presented here demonstrates the potential exposure as serious. It also flags the importance of within household variations in concentrations of ongoing hazards. Certainly airborne toxin with respiratory exposure pathways are particularly harmful indoors where the most time is spent. The percent of time by period of the day and eleven activities is presented in Table 1.

In Silva <u>et al</u> (1985), an activity systems model is developed to estimate potential exposure related to 60hz electrical fields adjacent to long-distance high voltage power lines. Using time budget data, the model simulates the activities of farmers and others who engage in outdoor activities near high voltage power lines. By combining the electrical properties of the transmission line with the activity data, estimates of annual kilovolts/meter-hour are generated.

<u>Sudden Impact Hazards and Emergency Management</u>

Exposure rates for more sudden hazards may also be estimated as a function of the time-space distribution available in time use data. The consequences of sudden impact hazards such as earthquakes, tornados, flash floods and toxic chemical spills are directly related to how we use our time. For example, mid-day earthquakes are likely to have more human consequences in large cities than night-time or weekend events of similar size. This results from the daily migration of the workforce in communities to and from work locations. Tornadoes, floods other hazards impacting residential areas during night-time or weekend hours will threaten many more people than the same hazard during work-day periods. The risk of shipping toxic chemicals through some areas may be reduced by scheduling such activities to take advantage of time use information -- the associated catastrophic potential may be reduced.

The distribution of human populations may be estimated on the basis of time use data. Emergency planners may begin to anticipate the kinds of problems presented by emergencies occurring at different times of the day, and days of the week. Time budget analysis shows that the often dreaded night time disaster may prove less ominous than anticipated. While darkness no doubt hampers mitigation efforts, households are most likely to be together at home during these periods. In as much as households prefer to take emergency mitigation actions together, (Rogers and Nehnevajsa 1984, Mileti et al. 1975), the family unit is already united and can concentrate directly on adaptive emergency response.

In addition to the relative advantage of inadvertently being in a comparatively safe location during the impact of a sudden impact hazard, emergency management is enhanced by a thorough understanding of the time budget implications for dissemination of the warning message, notification of appropriate emergency activity, and the likelihood of adaptive mitigative action. The window provided by the electronic media is directly related to an emergency manager's ability to disseminate emergency warning to potentially impacted communities. The relatively limited media window during the day-light and dead-of-night hours underscores the need for alerting systems to get people "tuned in" to their radios and televisions. Planning for the late-night dissemination of warning is greatly enhanced through the probabilistic modelling of the processes and an appreciation of the proportion of the population awake during the affected periods. A detailed analysis of the contagion of the warning in the dead-of-night hours based on the proportion of the population awake, the likelihood of arousal among those sleeping, the likely dissemination of warning within households, the likelihood of inter-household contact, household size, and age distribution has been developed to provide emergency management insight for nuclear power plant emergency plans (Nehnevajsa 1985).

CONCLUSIONS

This paper has highlighted a few uses of time budget data and analysis for risk management. The more global categories of activity used here were designed to demonstrate the overall usefulness of the time budget approach to risk management. Three important aspects of risk management are highlighted; 1) the estimation of exposure to ongoing hazards, 2) estimating the probability of exposure to the catastrophic potential of more sudden hazards, and 3) examining emergency management implications of population distribution throughout the day.

While the rich data base provided by the time budget approach has been aptly demonstrated, the depth of the risk management potential has been but touched upon. Specific risk potentials will require detailed analysis of particular activities, the distribution among people, geographic location, day of the week, season of the year and time of day. Time budget data provide such richness and depth in part because they reflect action; not merely attitudes bearing on acceptability, but action reflecting varying degrees of acceptability. Perhaps in this vein time budget data may be used to provide foundation for public perception of risk and its associated acceptability. In any event, daily exposure to hazards of various kinds may be appropriately traced through time budget data. Through careful examination of daily time budgets, legislators, regulators, and risk managers may better focus: a) attention on hazards with the most significant exposure-consequence implications, b) appropriate and effective standards may replace blanket assumptions of safety, c) risk mangers may focus limited resources on issues of great catastrophic potential, and d) emergency managers may better prepare for the most likely event-exposure-consequence chains, by taking advantage of likely daily activities in specific locations. For it is through these actions that risk managers can earn the public's confidence and trust, so much a part of effective risk management.

We have taken a positive view about the potential usefulness of time budget data and analysis for risk management applications; however, some caveats are required. Most of the applications we have discussed have not been tried in practice. Hence, only a few risk assessments have been based on time budget analyses, to our knowledge, and these have been covered herein. Most of what we have presented remains untried, and therefore must be subjected to the validation of real applications. While our analysis suggests that the time budgets of adult Americans are very similar across demographic groups, seasons of the year, and other variables, it is certainly possible that subpopulations may exhibit quite distinct time budgets, and are too infrequently represented in the Michigan data base to influence the overall results, or to be analyzed as a separate group[4]. For example, the time budgets of farmers <u>are</u> somewhat different from other working subpopulations, because farmers work longer hours than most other Americans (Silva <u>et al</u> 1985). In summary, we believe our suggestions will prove to be a valued contribution to risk management, while understanding that much more needs to be done.

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4. In analyses not reported here, we have learned that the time budgets of adult Americans do not vary greatly when we compare seasons, men and women, young, middle aged and the elderly for the eleven types of activity considered here. We are continuing these analyses to discover the variables that significantly modify the structure of time budgets.

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