# A Literature Review of the Research on Take-Over Situation in Autonomous Driving

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**Abstract.** In order to understand driver's response time from automatic driving to manual driving and driving behavior after taking over in the complex traffic environment, and influencing factors of driver's driving switching process, this paper systematically combs the common experimental situations in the research of the take-over situation in autonomous driving, and analyzes the characteristics of the take-over situation, driver's behavior characteristic, take-over time and driving performance. We hope in the future, autonomous driving take-over procedure could balance safety and experience for drivers.

**Keywords:** Autonomous driving · Take-over · Situational awareness · Driving behavior · Driving workload

## 1 Introduction

In recent years, information technology is playing an important role in traditional automobile industry. Artificial intelligence, control algorithms and sensors is continuously developing, autonomous driving achieved rapid development, autonomous driving cars improved driving safety, comfort and efficiency. Various driving assistance systems are constantly developing and come into use. The increasing of intelligence has become a trend in automobile industry. Chris Urmson, director of the Google's former autonomous driving car business unit, believes that "when people enjoy themselves in the car, they couldn't always get the driving done safely." According to statistics, 75% of traffic accidents were caused by human, while autonomous driving technology is a technology designed to release human from the traffic system [1]. With the continuous development and improvement of technology, autonomous driving technology would come to be applied in practice, people could travel freely without worrying about accidents made by human.

According to the classification standard established by the American Society of Automotive Engineers (SAE) [2]. Autonomous driving is divided into 6 levels: No Automation (L0); Driver Assistance (L1); Partial Automation (L2); Conditional Automation (L3); Highly automation (L4); Fully automation (L5). At present, Chinese


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legal [3] provisions only L1 self-driving vehicles with automatic steering or automatic acceleration and braking functions, as well as L2 self-driving vehicles with automatic steering and automatic acceleration and braking functions could be driven on public roads. Autonomous driving system of L3 and above requires human intervention, and it will be a difficult problem to define clearly who should take the responsibility for driving by vehicle or driver [4].

July 2017, Audi released Audi A8, which is the first vehicle with an L3-class autopilot system, and it had the highest level of autonomous driving capability in production models all over the world. In L3 autonomous driving, driver does not need to pay attention to the driving environment at all times, and perform non-driving tasks (music, games, etc.). Meanwhile the autonomous driving system cannot handle all driving tasks, when system recognizes that the current situation could not be processed, it would present the driver demand with visual or audible information, to prompt driver to take over the vehicle again. The principal of main driving task is transferred from the autonomous driving vehicle to driver, this is called the take-over technique in autonomous driving. According to the definition of Bundesanstalt fur StraBenwesen, highly automated driving constitutes a system that takes over a complete driving task for a specific time. Driver doesn't need to monitor the system, but if the system requires, driver should take over the driving task. During the take-over process, driver must have hands and feet back the controlling to state, restore the situation awareness, and make decisions and reactions after taking over [5].

During the process of switching from autonomous driving to manual driving, driver needs a certain period of time to re-enter the driving state and resume driving ability, and this adaptation period is much likely to cause an accident [6]. In 2012, during the road test of Google Unmanned Vehicles, people promised to keep an eye on the road conditions during the test so that they can take over the driving in time when an emergency occurs, but in fact many people are distracted to do all sorts of things in the road test. In the study of autonomous driving, this classic problem is called the "hands-off problem" [7]. It can be seen that non-driving tasks have a great impact on the take-over process and quality. In addition, when studying the take-over problem in autonomous driving, traffic conditions, user's situational awareness, etc. are closely related to driving take-over [8]. Many scholars have carried out a series of studies on the behavior of drivers during the take-over process, mainly in terms of take-over time and driving performance after take-over. For example, when explored the appropriate time point for guiding driver's attention back to the driving task, Gold et al. found the shorter the take-over request time, the shorter the time taken by the driver take over the vehicle, and the faster the driver's reaction and decision, the worse the driver's take-over quality [9]. After conducting experiments, Strand et al. found that the intelligent level of the vehicle and the degree of system failure have an impact on the driving performance of driver after taking over. The higher the level of automation, the greater the reduction in driving performance [10].

The process of taking over affects the subsequent driving safety, and many factors influence this process. Take-over situation is very important as an objective condition, and it is also an important experimental condition for many scholars to conduct driving take-over research. This paper will analyze the driving take-over problem in autonomous driving from the perspective of take-over situation, specifically by the take-over

situational characteristics, the driver's behavioral characteristics, take-over time and driving performance. Combined with user's psychological and behavioral characteristics, this paper hope to provide a theoretical reference for the future interaction design for take-over of highly autonomous driving.

## 2 Take-Over Situation

### 2.1 Capability Limits of ADAS

When people drive, the ADAS (Advanced Driver Assistant System) of the autonomous driving car receives various types of information from roads, environments, pedestrians, signs, and equipment. The autonomous driving system analyzes and makes decisions based on the received situational information, and ultimately controls the vehicle. However, the road surface, road conditions, weather and other factors are complex and changeable. In some scenarios, ADAS cannot identify the situation information accurately, or the ability of the automatic driving system is insufficient to deal with the situation, then the system is difficult to make accurate operational decisions. The take-over system of vehicle is triggered, and driving authority is handed over to the driver, driver starts to respond to the situation.

Taking Audi A8 as an example, driver can perform other tasks besides the main driving task in the car, and even can remove the hands and feet from the steering wheel, the brake and the accelerator pedal. However, in some situations, driver still needs to respond to the control switch request from autonomous driving system at any time. For example, the vehicle is close to the high-speed exit and needs to change lanes to drive off the highway, the front vehicle with a slow speed, the vehicle needs to give way for an ambulance at the rear, temporary construction of road and the lane suddenly becomes less, and there is a traffic accident in front.

Lu explored the driving take-over response characteristics of young drivers, and the impact of take-over request time and visual tasks on the take-over time. The study set a driving take-over situation: when the subject is doing the visual tasks during the autonomous driving process, an anchored vehicle suddenly appears in front of the lane. The autonomous driving system will send a prompt message to the driver "autonomous driving is about to expire, please take over!", and display a text prompt icon on the central display screen. After hearing the tone, driver needs to quickly press the toggle button to switch the vehicle from the autonomous driving mode to the manual mode. The study considers the collision avoidance time between the driving vehicle and the front anchored vehicle as the take-over request time. The experimental results show that the take-over time with secondary tasks increase significantly compared to that without secondary tasks. When handle the take-over scenarios with an obstacle in the front, the participants tended to apply the operation of combined brake and swerve [11].

## 2.2 Common Situations of Autonomous Driving Take-Over

There are four common situations in the experimental research related to autonomous take-over [12–15]. First, the travel planning changes, the driver should choose a specific route; Second, the road markings can't be recognized, such as the lane line or the turning mark is ambiguous; third, the vehicle itself doesn't work, the sensor fails, the software is wrong, etc.; Fourth, the road construction and road conditions become complicated and it is difficult for vehicles to ensure safe driving. Based on the consideration of the current automatic driving system restrictions, Kuehn et al. set these four scenarios [16]. In scenario 1, the driver is required to take over control of the vehicle to select a particular route or leave the highway. There are no other vehicles within 5–5.25 s after the take-over request is issued, and the navigation arrow appears on the head up display, prompting the driver to change lanes. In scenario 2, the vehicle is no longer able to turn safely enough because the system can't recognize the lane markings clearly, so the system transfers control to the driver. There is a car 250-m - far in front of the driver's vehicle. The car initially maintains a speed of 120 km/h. After 5–5.25 s, the vehicle in front is braked until it reaches a speed of 80 km/h and maintains the speed. In scenario 3, the vehicle is no longer able to turn safely enough due to sensor failure or software error, thus transferring control to the driver. The only difference between scenario 3 and scenario 2 is that there is no absence of lane markings (Fig. 1).

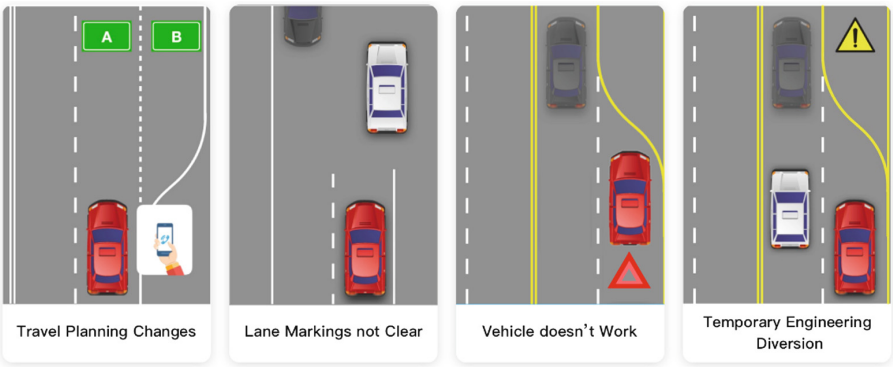


**Fig. 1.** Four common situations in the experimental research related to autonomous take-over.

In the scenario 4, due to road works, the vehicle can no longer be turned safely enough, so control is transferred to the driver. The autonomous system issues a high traffic density alert while decelerating the driver's vehicle based on the speed limit shown on the road sign, from 120 km/h to 60 km/h. In addition to setting up road works 300 km away from the point of take-over request, at the same time, the experiment simulate stationary vehicle in driving, and the stationary vehicle was 175 m away from the take-over request point. From the literature, it was found that multi-lane highways were used as the basis context for experimental simulation in many take-over

scenarios. As in the four scenarios mentioned above, the take-over situations are all on the highway. During autonomous driving, the automation system keeps 60 m away from the vehicle in front. Once the distance is less than 60 m, the autonomous system is activated with an audible warning signal. The results of the study indicate that the automation system should provide the current road conditions to the driver as early and clear as possible, and if 90% of drivers are required to respond correctly, the take-over time should over 8 s. During the take-over process, the automation system should always control the vehicle safely until the driver takes over explicitly.

A summary of the above scenarios reveals that the situation in which the take-over takes place has two characteristics. First, the complexity of the situation is high, such as lane change, complicated road conditions of so many vehicles, unpredictable trajectory of pedestrian or non-motorized vehicles, and irregular driving behavior from other vehicles. Second, situational urgency is in high level, such as the situation of serious rear-end collisions when the vehicle ahead has emergency brakes, and the general conflict situation in which other vehicle suddenly cut the line. In the future, we could start from these scenarios and define the situation that requires driving take-over more clearly. This also helps to balance the safety and experience when driver is in autonomous driving context.

In addition, above context are take-over scenarios which will be adopted in the current research, all of them belong to the case when the automatic driving system initiative proposes to take over the request. While in the actual driving process, driver could also take the initiative for a take-over request, for getting fun in driving, or not satisfied with the speed of the automatic driving system, and soon in the future, we can start a research base on the analysis above.

## 3 Driver's Behavior Characteristics

### 3.1 Situation Awareness

Different drivers have different behavior and responses in different road conditions, especially in dangerous situations, such as traffic flow density, relative speed of the vehicle itself and surrounding vehicles, and distance between vehicles, these external factors and internal factors like driver's attention state can greatly influence driver's decision. Therefore, the perception of the environment, the intent recognition of surrounding vehicles and the prediction of vehicle track are important for driver to make decisions and corresponding behavior. It needs driver to maintain a good situation awareness. Situation awareness in the context of autonomous refers to the driver's perception and understanding of all environmental factors including time and space during the autonomous driving process, and the prediction of what's happening around [17].

Zhang Yu's interviews with three autopilot users (novice users, intermediate users and expert users), and found that during driving autonomous vehicles, drivers are prone to have four characteristics, driving distraction, passive fatigue, over-trust of autonomous driving system, and driving skill degradation [18]. Driving distraction is expressed by the driver's attention and cognitive resources shifting from basic driving

tasks such as controlling the car, maintaining the lane, and monitoring the road conditions to non-driving tasks. Passive fatigue is manifested by a drastic reduction in driving workload, resulting in a cognitive load that is too low to fall into passive fatigue. Excessive trust is manifested by the driver's over-estimation and over-reliance on the auto-driving function after using the autonomous system for a period of time, which also further increases the tendency to drive distraction. Degradation of driving skills is manifested by the reduced flexibility and driving cognitive skills required to manually complete mission success and safety after prolonged use of the autonomous driving function. All of these four features are extremely detrimental to the driver's safe driving (Fig. 2).

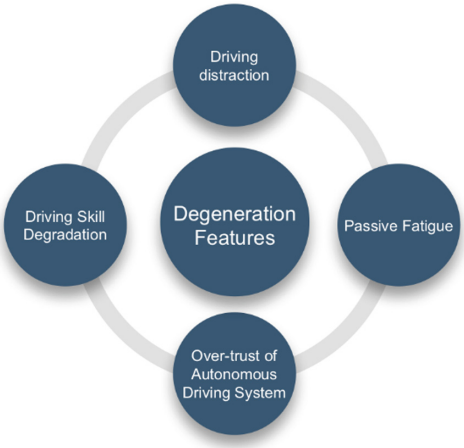


**Fig. 2.** Four characteristics of driving degradation.

When driving main task is handed over to the system, driver's attention will be diverted from driving task, and only a small amount of attention resources will be used to maintain an understanding of the vehicle's state and road conditions, and the attention to the situation will be reduced. So the "hands-off problem" of the Google testers mentioned above has arisen. At this point, driver receives a take-over prompt, driver will be very surprised and need more time to come back to the driving state, and the increase in reaction time and transfer of the attention object lead to the risk in driving. Jamson et al. found that vehicles with higher levels of autonomous driving ability can better reduce accidents and human brain load, but driver's situational awareness will be lower [19]. There is no doubt that it is very dangerous in the event of an emergency.

### 3.2 Driver's Switching Mode

In the study of the driving behavior during the take-over of autonomous driving vehicles in dangerous traffic situation, Niu used the driving speed, headway distance,

vehicle lateral control and vehicle steering behavior as the driver's driving performance assessment. It was found that after receiving the danger warning, driver would have two different switching modes, driver switched immediately and regained the control of the vehicle quickly, the other is to monitor the road and vehicle information for a period of time [20]. This situation of monitoring the situation after receiving the take-over prompt mainly occurs when driver is in a relaxed state at present, and the "person" in charge of the main driving task is an automatic driving system. At this time, it is necessary to switch its own alert/wake level before the take-over, identify and analyze the driving situation in which it is located.

Human factors in the autonomous take-over process will have an impact on driving safety. First of all, in the automatic driving state, if the driving task is too easy, driver can easily enter the passive fatigue due to the low cognitive burden, and the boring driving process will cause the driver to participate in non-driving tasks more, such as social entertainment. Then it leads to driving distraction. Secondly, because driver's main attention resources in the automatic driving process are not concentrated on the vehicle and the road situation, the situation awareness is reduced, and when the automatic system exits and the switching control request is issued, the driver may be frightened by unexpected state changes or prompts. At the same time, insufficient level of situation awareness may cause confusion about the driving mode. In addition, driver may also be overly dependent on the autonomous driving system, reduce the trust in automatic driving by frequent warning messages.

## 4 Take-Over Time and Driving Performance

### 4.1 Take-Over Time

After receiving the take-over request from the vehicle, the driver needs to take over the vehicle again, and driver's decision on the situation and the control of the vehicle will be affected. Happee et al. studied the autopilot take-over by using Time to Collision (TCC) and the distance from the obstacle as an evaluation indicator of the emergency take-over operation. It was found that the autopilot would make the driver more likely delay in steering and brake intervention than the manual driving behavior [21].

The workload during driving is an important factor affecting the driver's take-over response time and driving performance. According to Yed's rule, too high or too low workload will both affect driving performance [22]. Merat et al. compared the driving performance between the driver experience on autonomous driving switch to manual driving and purely manual driving, found that drivers who have experienced autonomous driving have worse driving performance. This is because driver is in low workload during autonomous driving [23].

In studying the impact of non-driving tasks on driving take-over performance, it was found that the driver's distraction and tension can affect the reaction time and further affect the time taken by the driver to take over the vehicle. The reaction time required by driver to play the game is significantly greater than listening to music. Eriksson et al.'s research also shows that the driver's take-over reaction time is longer under the influence of the sub-tasks [24]. Zeeb et al.'s research has drawn different

conclusions. The experiment has studied the effects of different real sub-tasks (writing e-mails, reading news, watching videos) on the take-over operation, and the results show that the sub-tasks have no effect on driver's take-over time [25]. Comparing these above studies, it can be found that the conclusions of the two studies may be caused by factors such as the driver's own characteristics, the state before the take-over operation, and the urgency of the take-over situation. At the same time, the impact of the non-driving task on the driving take-over, take-over time and driving performance is difficult to strip, as Zeeb et al.'s research also shows that driving take-over will deteriorate the driving quality after taking over.

### 4.2 Driving Performance

In addition, traffic conditions can also have an impact on driving performance. Radlmayr et al. study the influence of different traffic situations and non-driving tasks on the take-over process during highly autonomous driving. The standardized visual Surrogate Reference Task (SuRT) and the cognitive n-back Task are used to simulate the non-driving related tasks, results show that take-over quality does not seem to significantly depend on varying the chosen non-driving related tasks prior to the take-over. On the other hand, it indicates a strong influence of the traffic situation on take-over time and quality. A higher criticality of driver behavior can clearly be observed in the situation which features a high traffic density [8].

At present, researchers have carried out a series of studies on the driving take-over behavior in autonomous driving, which focus on workload and traffic conditions. However, the research on driving operation characteristics under specific situation and driving sub-tasks on driving take-over time and driving performance are not deep enough. Researchers can do more comparison of the driver's operation data under different take-over situations, it will provide a more comprehensive theoretical basis for the study of driving take-over behavior.

## 5 Meaning of Driving Take-Over

Since the excessive or low workload during the autonomous driving process will both affect the take-over time and driving performance, which will affect the driving safety, the take-over system should design a better way for the driver to participate more in the driving task, pay attention to vehicle status and road traffic scenarios in order to maintain a good situation awareness. At the same time, it is necessary to design a better warning mode, indicating the current automatic driving status and its limitations, clearly and efficiently transmitting information, which is easy to be obtained by driver, avoid driver separating from the human-car-environment system. A study by Seppelt et al. found that giving driver a continuous message is more effective than a generic failure hazard warning [26].

The manner in which driver take-over system issues a switching request to the driver should balance the workload and urgency, not too early for the driver to interpret it as a false positive, but also not too late to catch the opportunity to switch the manually driven vehicle. The operation and reaction time during the process of taking

over the vehicle affects driver's subsequent driving safety, based on the diver's behavior characteristics under different take-over situations and take-over conditions, scholars can do further study on the way of request driver to take over the vehicle.

## 6 Conclusion

With the developing of various active safety technologies, highly autonomous driving cars will gradually become popular in the next decade, bringing significant social and economic benefits. While the higher the level of automation, the more important the human operator is. The existing research has found that the ADAS will lower driver's situational awareness and decreased control skills, workload and traffic conditions during the take-over process will also influence the take-over time and driving performance. In the context of the continuous development of autonomous driving, how to ensure the driving safety in the take-over situation while driver's participation in the driving main task is continuously reduced is a major difficulty in the future.

At present, research on the autonomous driving take-over does not involve the study of the stability of the vehicle under different take-over conditions. However, this is very important for the driving experience. In the future, scholars can carry out these researches, provides a richer theoretical basis for the rational design in driving take-over system, realize reliable, safe and interesting driving maneuver switching.

## References

1. Salmon, P.M., Regan, M.A., Johnston, I.: Human Error and Road Transport: Phase One – Literature Review. Highway Safety (2005)
2. SAE On-road Automated Vehicle Standards Committee: Taxonomy and Definitions for Terms Related to On-road Motor Vehicle Automated Driving Systems. SAE, Warrendale (2014)
3. 《Road Traffic Safety Law of the People's Republic of China》, Chap. II Sect. 2 Motor Vehicle Drivers (2011)
4. Editorial Department of China Journal of Highway and Transport: Review on China's Automotive Engineering Research Progress: 2017. China J. Highw. Transp. **30**(6), 1–197 (2017)
5. Radlmayr, J., Gold, C., Lorenz, L., Farid, M., Bengler, K.: How traffic situations and non-driving related tasks affect the take-over quality in highly automated driving. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 58, no. 1, pp. 2063–2067 (2014)
6. Russell, H.E.B., Harbott, L.K., Nisky, I., Pan, S., Okamura, A.M., Gerdes, J.C.: Motor learning affects car-to-driver handover in automated vehicles. Sci. Robot. **1**(1), 1–10 (2016)
7. Wang, Y.: Audi new A8 defining the future—analyzing Audi's new generation A8 autopilot technology. World Automob. **09**, 30–37 (2017)
8. Radlmayr, J., Gold, C., Lorenz, L., Farid, M., Bengler, K.: How traffic situations and non-driving related tasks affect the take-over quality in highly automated driving. In: Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting, pp. 2063–2067. SAGE Publications (2014)

9. Gold, C., Dambock, D., Lorenz, L., Bengler, K.: "Take Over!" How long does it take to get the driver back into the loop?. In: Proceedings of the Human Factors & Ergonomics Society Annual Meeting, pp. 1938–1942. SAGE Publications (2013)
10. Strand, N., Nilsson, J., Karlsson, M.A., Nilsson, L.: Semi-automated versus highly automated driving in critical situations caused by automation failures. Transp. Res. Part F: Traffic Psychol. Behav. **27**, 218–228 (2014)
11. Lu, G., Zhao, P., Wang, Z., Lin, Q.: Impact of visual secondary task on young drivers' take-over time in automated driving. China J. High. Transp. **31**(04), 165–171 (2018)
12. Maurer, M., Gerdes, J.C., Lenz, B., Winner, H.: Autonomes Fahren: Technische, rechtliche und gesellschaftliche Aspekte. Springer Vieweg, Heidelberg (2015). https://doi.org/10.1007/978-3-662-45854-9
13. Hillel, A.B., Lerner, R., Levi, D., Raz, G.: Recent progress in road and lane detection: a survey. Mach. Vis. Appl. **25**(3), 727–745 (2014)
14. Meyer, G., Beiker, S.: [HRSG]: Road Vehicle Automation. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-05990-7
15. Ziegler, J., et al.: Making Bertha drive—an autonomous journey on a historic route. IEEE Intell. Transp. Syst. Mag. **6**(2), 8–20 (2014). https://doi.org/10.1109/mits.2014.2306552
16. Kuehn, M., Vogelpohl, T., Vollrath, M.: Takeover times in highly automated driving (level 3). In: 25th International Technical Conference on the Enhanced Safety of Vehicles (ESV) (2017)
17. Feng, C., Wanyan, X., Chen, H., Zhuang, D.: Situation awareness model based on multi-resource load theory and its application. J. Beijing Univ. Aeronaut. Astronaut. **44**(07), 1438–1446 (2018)
18. Zhang, Y.: Research on Human-Machine Interaction Strategy Design of Automated Driving Take-over System Based on User Experience, pp. 21–30. South China University of Technology (2018)
19. Jamson, A., Meratn, N., Carsten, O., et al.: Behavioural changes in drivers experiencing highly-automated vehicle control in varying traffic conditions. J. Transp. Res. Part C **30**(5), 116–125 (2013)
20. Niu, J., Zhang, X., Sun, Y., Qin, H.: Analysis of the driving behavior during the takeover of automatic driving vehicles in dangerous traffic situations. China J. High. Transp. **31**(06), 272–280 (2018)
21. Happee, R., Gold, C., Radlmayr, J., et al.: Take-over performance in evasive manoeuvres. J. Accid. Anal. Prev. **106**, 211–222 (2017)
22. Coughlin, J., Reimer, B., Mehler, B.: Driver Wellness, Safety & the Development of an Aware Car. AgeLab, Boston (2009)
23. Merat, N., Jamson, A., Lai, F., et al.: Highly automated driving, secondary task performance, and driver state. J. Hum. Factors **54**(5), 762–771 (2012)
24. Eriksson, A., Stanton, N., Davis, K.: Takeover time in highly automated vehicles: noncritical transitions to and from manual control. Hum. Factors: J. Hum. Factors Ergon. Soc. **59**(4), 689–705 (2017)
25. Zeeb, K., Buchner, A., Schrauf, M.: Is take over time all that maters? The impact of visual-cognitive load on driver take-over quality after conditionally automated driving. J. Accid. Anal. Prev. **92**, 230–239 (2016)
26. Seppelt, B., Lee, J.: Making Adaptive Cruise Control (ACC) limits visible. J. Int. J. Hum.-Comput. Stud. **65**(3), 192–205 (2007)