SURVEY OF THE DRIVER'S REACTION TIME TO THE APPEARANCE OF A PEDESTRIAN ON AN UNREGULATED PEDESTRIAN CROSSWALK IN THE DARK

6th of April, 2022, New Jersey, USA

Annotation

This article examines the dependence of the driver's reaction time on the appearance of a pedestrian at an unregulated pedestrian crossing at night on the methods of the crosswalk's illumination: standard street lighting, dynamic light escorting pedestrians, and no lighting.

The survey was conducted using psychometric methods on synthetic data simulating driving a vehicle. The obtained statistical data is analyzed and the interpretation of the results is provided. According to the survey, the use of dynamic light tracking of pedestrians on an unregulated pedestrian crosswalk significantly increases the pedestrians' safety.

Introduction

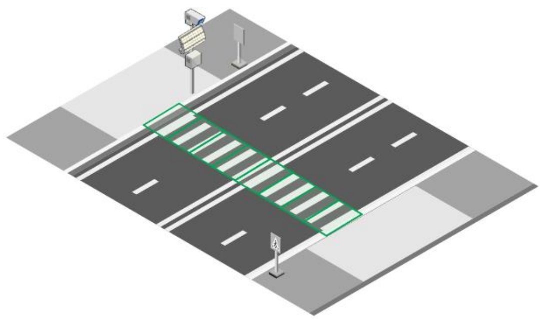
Unregulated pedestrian crossings are one of the most accident-prone sections of the road. Accidents often occur since the driver does not notice the pedestrian or notices him too late to be able to slow down in time without creating an emergency on the road. Two main reasons for such situations are 1) poor visibility in the dark, aggravated by precipitations (heavy rain or snow), and 2) decreased concentration due to monotony or fatigue. According to statistics, accidents involving people in the dark account for about 40% of all accidents, which exceeds the daily rate by about 10%, and the risk of fatal injuries in the evening and at night increases by almost 50%[i] [ii].

The following hypothesis is put forward in this article. At night, the driver's reaction time to the pedestrian appearance on an unregulated crosswalk equipped with a dynamic light pedestrians escorting system is significantly lower than the driver's reaction time to the pedestrian appearance on an unregulated crosswalk with standard street lighting or on an unlit crossing.

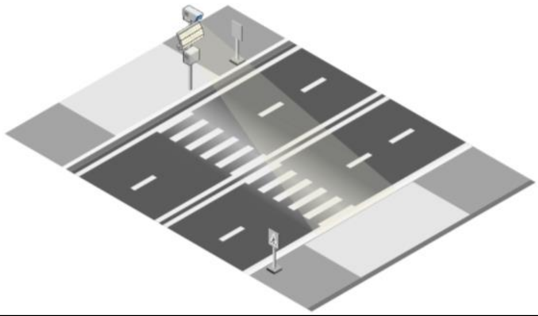
General description of the crosswalk dynamic lighting system

The spotlight consists of a group of LED modules that illuminate sections of the pedestrian crossing.

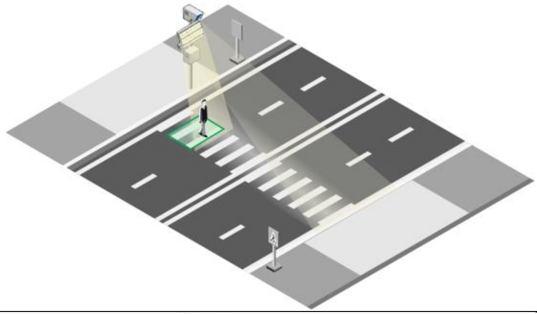
Each LED module is made for the illumination of a certain section of the pedestrian crosswalk.



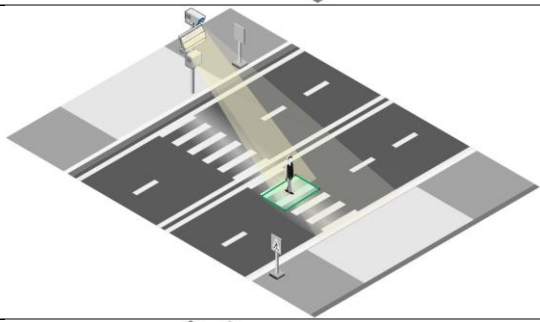
In standby mode, i.e. if there are no pedestrians on the crossing, an LED spotlight provides static lighting of the pedestrian crosswalk at reduced power.



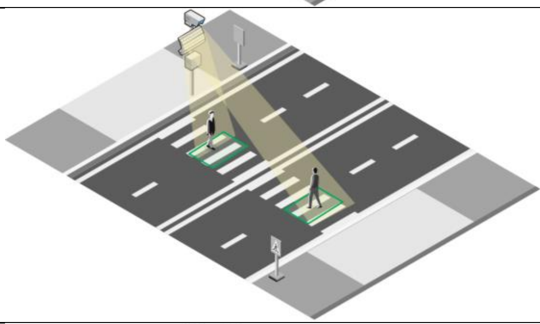
When a pedestrian is detected in the control area, the system switches to active mode. The dynamic illumination mode with the maximum power of the LED module corresponding to the current pedestrian area is activated. The static illumination of the remaining modules continues to operate.



Continuous light escorting of a moving pedestrian on a pedestrian crosswalk is provided.



The system also provides dynamic lighting for several pedestrians (or groups of pedestrians) moving at different speeds and in opposite directions.



After the pedestrian leaves the detection area, the spotlight returns to standby mode.

Therefore, the dynamic lighting system ensures the focus of the driver’s attention precisely on the pedestrian rather than on the road infrastructure illumination.

Description of the psychometric test

The 3D video simulating the process of driving a vehicle was developed to assess the impact of illumination methods or the effect of lack of lighting on the driver's reaction time to the pedestrian on an unregulated pedestrian crosswalk.

For 16 minutes, the vehicle moves along a linear section of the road with a changing speed from 49.7 mph (80 km/h) to 93.2 mph (150 km/h), crossing 75 pedestrian crosswalks.

The pedestrian crosswalk can be

a) unlit:

b) equipped with standard street lighting:

c) equipped with dynamic lighting escorting pedestrian systems:

Moreover, the crosswalk may be either empty, or there may be one or more pedestrians on it.

A short video clip (mp4) of the 3D video is available: https://www.dropbox.com/s/b3cvb01y0hseo27/videoclip.mp4?dl=0

Metadata was prepared for the video, containing information on when pedestrians appear on the crosswalk.

Lighting type	Cross Road#	Time of day	Pedestrian in the frame	click 1	time difference: click/pedestrian 1	click 1 14.03.22	time difference: click/pedestrian 1 14.03.22	click 2 14.03.22	time difference: click/pedestrian 2 14.03.22	click 2 15.03.22	time difference: click/pedestrian 2 15.03.22	click 3 14.03.22	time difference: click/pedestrian 3 14.03.22	click 3 15.03.22	time difference: click/pedestrian 3 15.03.22	click 4 14.03.22	time difference: click/pedestrian 4 14.03.22	click 5 14.03.22	time difference: click/pedestrian 5 14.03.22
Lighting + escorting pedes	33	evening	7:12:40	7:14:12	0:01:32	7:14:02	0:01:22	7:14:16	0:01:36	7:14:24	0:01:44	7:15:07	0:02:27	7:14:50	0:02:10	7:14:14	0:01:34	7:13:52	0:01:12
Standard street lighting	34	evening	7:21:55	7:27:36	0:05:41	7:22:38	0:00:43	7:24:43	0:02:48	7:23:31	0:01:36	7:26:19	0:04:24	7:26:14	0:04:19	7:24:48	0:02:53	7:24:16	0:02:21
Standard street lighting	35	evening	7:32:52	7:35:50	0:02:58	7:35:43	0:02:51	7:35:48	0:02:56	7:35:31	0:02:39	7:36:33	0:03:41	7:36:12	0:03:20	7:35:45	0:02:53	7:35:07	0:02:15
Standard street lighting	36	evening	7:42:28	7:45:55	0:03:27	7:44:16	0:01:48	7:44:02	0:01:34	7:42:43	0:00:15	7:46:09	0:03:41	7:45:38	0:03:10	7:45:04	0:02:36	7:44:04	0:01:36
Lighting + escorting pedes	37	evening	7:42:28	7:45:55	0:03:27	7:44:16	0:01:48	7:44:02	0:01:34	7:42:43	0:00:15	7:46:09	0:03:41	7:45:38	0:03:10	7:45:04	0:02:36	7:44:04	0:01:36
Lighting + escorting pedes	38	evening	8:02:57	8:05:19	0:02:22	8:04:19	0:01:22	8:03:09	0:00:12	8:03:48	0:00:51	8:05:48	0:02:51	8:04:48	0:01:51	8:05:02	0:02:05	8:03:24	0:00:27
No lighting	39	evening	8:08:40	8:12:48	0:04:08	8:11:09	0:02:29	8:11:36	0:02:56	8:11:33	0:02:53	8:13:21	0:04:41	8:12:28	0:03:48	8:13:33	0:04:53	8:10:55	0:02:15
No lighting	40	evening	8:23:28	8:26:04	0:02:36	8:25:55	0:02:27	8:26:09	0:02:41	8:25:28	0:02:00	8:26:12	0:02:44	8:26:16	0:02:48	8:26:04	0:02:36	8:25:52	0:02:24
Lighting + escorting pedes	41	evening	8:29:48	8:35:02	0:05:14	8:32:16	0:02:28	8:33:26	0:03:38	8:32:55	0:03:07	8:36:07	0:06:19	8:35:33	0:05:45	8:35:09	0:05:21	8:30:28	0:00:40
No lighting	42	evening	8:49:02	8:51:24	0:02:22	8:51:21	0:02:19	8:51:21	0:02:19	8:51:02	0:02:00	8:52:07	0:03:05	8:51:40	0:02:38	8:51:38	0:02:36	8:49:55	0:00:53
Standard street lighting	43	evening	8:53:28	8:59:16	0:05:48	8:57:14	0:03:46	8:58:09	0:04:41	8:55:52	0:02:24	8:59:26	0:05:58	8:58:16	0:04:48	8:58:16	0:04:48	8:54:57	0:01:29
No lighting	44	evening	9:08:55	9:11:21	0:02:26	9:12:07	0:03:12	9:11:57	0:03:02	9:11:55	0:03:00	9:12:28	0:03:33	9:11:33	0:02:38	9:12:07	0:03:12	9:10:31	0:01:36
No lighting	45	evening	9:21:40	9:24:36	0:02:56	9:24:24	0:02:44	9:24:07	0:02:27	9:22:45	0:01:05	9:24:48	0:03:08	9:24:12	0:02:32	9:24:07	0:02:27	9:23:04	0:01:24
Standard street lighting	46	evening	9:37:00	9:40:50	0:03:50	9:40:19	0:03:19	9:41:00	0:04:00	9:40:09	0:03:09	9:42:00	0:05:00	9:41:14	0:04:14	9:41:26	0:04:26	9:39:07	0:02:07
Standard street lighting	47	evening	9:44:23	9:47:38	0:03:15	9:46:40	0:02:17	9:46:57	0:02:34	9:46:50	0:02:27	9:48:19	0:03:56	9:47:38	0:03:15	9:48:14	0:03:51	9:46:52	0:02:29
Standard street lighting	48	evening	9:52:28	9:54:19	0:01:51	9:53:40	0:01:12	9:53:24	0:00:56	9:53:14	0:00:46	9:54:40	0:02:12	9:54:14	0:01:46	9:54:50	0:02:22	9:54:04	0:01:36
Lighting + escorting pedes	49	evening	10:03:14	10:06:00	0:02:46	10:04:36	0:01:22	10:04:24	0:01:10	10:04:21	0:01:07	10:07:09	0:03:55	10:06:31	0:03:17	10:06:16	0:03:02	10:04:19	0:01:05
No lighting	50	evening	10:22:21	10:25:04	0:02:43	10:25:36	0:03:15	10:25:21	0:03:00	10:25:12	0:02:51	10:27:04	0:04:43	10:26:57	0:04:36	10:26:40	0:04:19	10:25:07	0:02:46
Standard street lighting	51	evening	10:47:16	10:48:33	0:01:17	10:48:36	0:01:20	10:49:19	0:02:03	10:48:55	0:01:39	10:48:55	0:01:39	10:48:50	0:01:34	10:49:24	0:02:08	10:49:24	0:02:08
Lighting + escorting pedes	52	evening	11:03:16	11:03:48	0:00:32	11:04:21	0:01:05	11:04:12	0:00:56	11:03:50	0:00:34	11:04:28	0:01:12	11:04:00	0:00:44	11:07:40	0:04:24	11:03:50	0:00:34
No lighting	53	evening	11:26:36	11:28:48	0:02:12	11:29:19	0:02:43	11:29:07	0:02:31	11:29:16	0:02:40	11:29:55	0:03:19	11:29:43	0:03:07	11:29:28	0:02:52	11:28:52	0:02:16
Lighting + escorting pedes	54	evening	11:39:24	11:41:55	0:02:31	11:40:40	0:01:16	11:41:09	0:01:45	11:40:50	0:01:26	11:41:43	0:02:19	11:41:52	0:02:28	11:41:31	0:02:07	11:40:43	0:01:19
No lighting	55	evening	11:51:21	11:54:02	0:02:41	11:53:38	0:02:17	11:53:48	0:02:27	11:53:31	0:02:10	11:54:24	0:03:03	11:54:02	0:02:41	11:54:04	0:02:43	11:53:04	0:01:43
No lighting	56	evening	12:01:31	12:03:57	0:02:26	12:05:14	0:03:43	12:05:45	0:04:14	12:04:28	0:02:57	12:06:00	0:04:29	12:04:21	0:02:50	12:08:07	0:06:36	12:04:02	0:02:31
No lighting	57	evening	12:20:21	12:22:28	0:02:07	12:22:50	0:02:29	12:23:02	0:02:41	12:22:04	0:01:43	12:23:48	0:03:27	12:23:02	0:02:41	12:23:16	0:02:55	12:22:45	0:02:24
Lighting + escorting pedes	58	evening	12:33:33	12:34:50	0:01:17	12:34:43	0:01:10	12:34:43	0:01:10	12:34:28	0:00:55	12:35:09	0:01:36	12:35:21	0:01:48	12:35:48	0:02:15	12:34:38	0:01:05
Standard street lighting	59	evening	12:41:52	12:48:26	0:06:34	12:43:21	0:01:29	12:45:16	0:03:24	12:43:57	0:02:05	12:47:26	0:05:34	12:46:43	0:04:51	12:45:38	0:03:46	12:44:24	0:02:32
Standard street lighting	60	evening	12:52:52	12:56:19	0:03:27	12:56:04	0:03:12	12:56:28	0:03:36	12:55:43	0:02:51	12:56:16	0:03:24	12:56:21	0:03:29	12:56:14	0:03:22	12:56:16	0:03:24
Standard street lighting	61	evening	13:03:28	13:06:50	0:03:22	13:04:55	0:01:27	13:05:02	0:01:34	13:04:43	0:01:15	13:06:36	0:03:08	13:06:16	0:02:48	13:05:09	0:01:41	13:04:07	0:00:39
Lighting + escorting pedes	62	evening	13:03:26	13:09:45	0:06:19	13:05:55	0:02:29	13:08:38	0:05:12	13:06:02	0:02:36	13:10:14	0:06:48	13:09:45	0:06:19	13:10:45	0:07:19	13:08:57	0:05:31
Lighting + escorting pedes	63	evening	13:23:02	13:26:12	0:03:10	13:24:04	0:01:02	13:24:57	0:01:55	13:24:33	0:01:31	13:25:50	0:02:48	13:26:12	0:03:10	13:24:21	0:01:19	13:23:43	0:00:41
No lighting	64	evening	13:30:28	13:33:07	0:02:39	13:32:00	0:01:32	13:32:09	0:01:41	13:31:57	0:01:29	13:33:14	0:02:46	13:33:16	0:02:48	13:33:45	0:03:17	13:31:24	0:00:56
No lighting	65	evening	13:43:50	13:45:52	0:02:02	13:46:26	0:02:36	13:46:04	0:02:14	13:46:04	0:02:14	13:46:40	0:02:50	13:46:33	0:02:43	13:46:40	0:02:50	13:46:07	0:02:17
Lighting + escorting pedes	66	evening	13:50:14	13:55:40	0:05:26	13:53:26	0:03:12	13:55:00	0:04:46	13:54:24	0:04:10	13:55:31	0:05:17	13:55:40	0:05:26	13:56:40	0:06:26	13:54:36	0:04:22

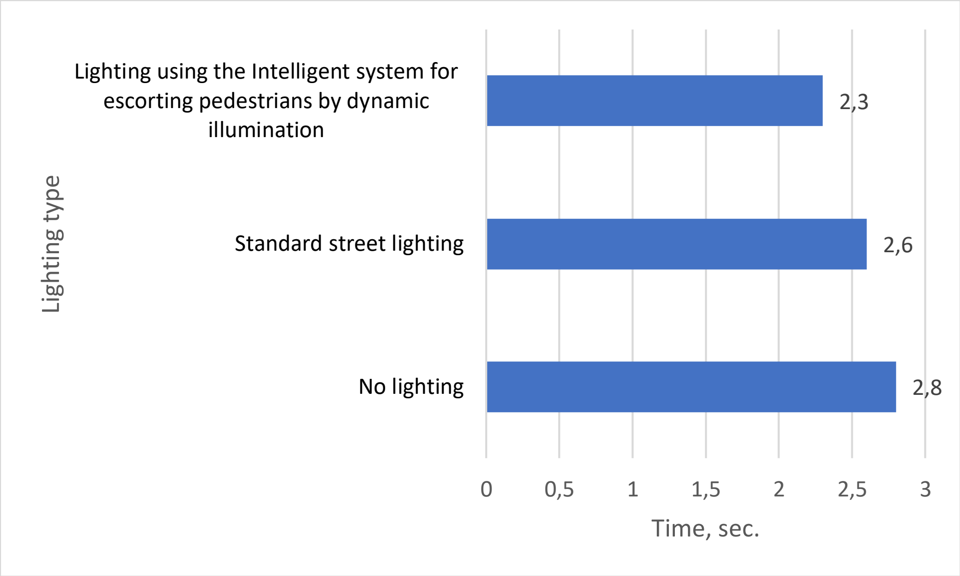
The examinee's task is to whenever he notices a pedestrian on the crosswalk, press the button on the keyboard. As a result, information about the exact reaction time to the pedestrian appearance is saved.

12 people from 22 to 56 years old took part in the study. Of these, 10 are men (83.3%) and 2 are women (16.6%). The average age of the examinee is 32 years. Every examinee took the test twice: in the morning rested and in the evening in a state of fatigue.

Data analysis and interpretation of results

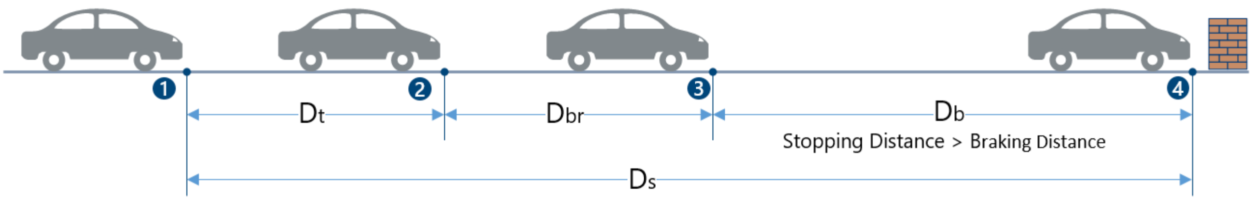
Based on the data obtained (the exact reaction time of each of the examinees to the appearance of pedestrians) the average reaction time of the driver to the pedestrian appearance at each of the three types of crosswalks was calculated.

The average reaction time of the driver to the appearance of a pedestrian, depending on the type of pedestrian crossing lighting:



Let's consider the obtained values from the standpoint of the stopping path, i.e. distance the vehicle has traveled from the moment when the driver detected the danger to a complete stop. The stopping distance consists of the thinking distance and the braking distance. The braking distance consists of the brake reaction distance and the path of braking itself.

The vehicle's stopping distance



Components of the stopping distance:

Dt - thinking distance

Dbr - brake reaction distance

Db - braking distance

Ds - stopping distance

The stopping distance is calculated by the formula:

$$S = (t_d + t_b)v + \frac{kv^2}{2g\varphi},$$

where t_d is driver reaction time, t_b is brake system response time, v is vehicle speed, k is braking efficiency coefficient, g is the acceleration of gravity, and φ is adhesion coefficient.

Let's make calculations using the example of a vehicle moving on a dry, wet, or icy road at a speed of 30 mph or 70 mph. The average value of the braking efficiency coefficient of a passenger vehicle k=1.2. Average brake system response time for hydraulic power $t_b = 0.2$. The adhesion coefficient φ on an asphalt road is shown in Table 1 below.

Table 1. Adhesion coefficient for different road surfaces

Road surface	**Adhesion coefficient**
Dry	0.8
Wet	0.4
Snow/ ice	0.2

Tables 2-4 below show the calculated values of the stopping distance and driver's thinking distance in different conditions.

Table 2. Calculated values for a crosswalk equipped with a dynamic pedestrian escorting system

Speed of vehicle, mph	Road Surface	Thinking Distance, ft.	**Stopping Distance, ft.**
30	Dry	101.2	**155.1**
	Wet		**200.2**
	Snow/Ice		**290.5**
70	Dry	236.1	**502.3**
	Wet		**747.9**
	Snow/Ice		**1239.1**

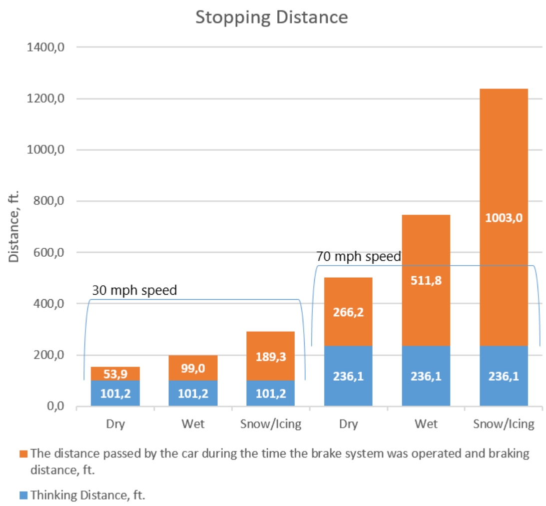


Table 3. Calculated values for the crosswalk illuminated by standard street lighting

Speed of vehicle, mph	Road Surface	Thinking Distance, ft.	**Stopping Distance, ft.**
30	Dry	114.4	**168.3**
	Wet		**213.4**
	Snow/Ice		**303.6**
70	Dry	266.9	**533.1**
	Wet		**778.7**
	Snow/Ice		**1269.9**

Table 4. Calculated values for an unlit crosswalk

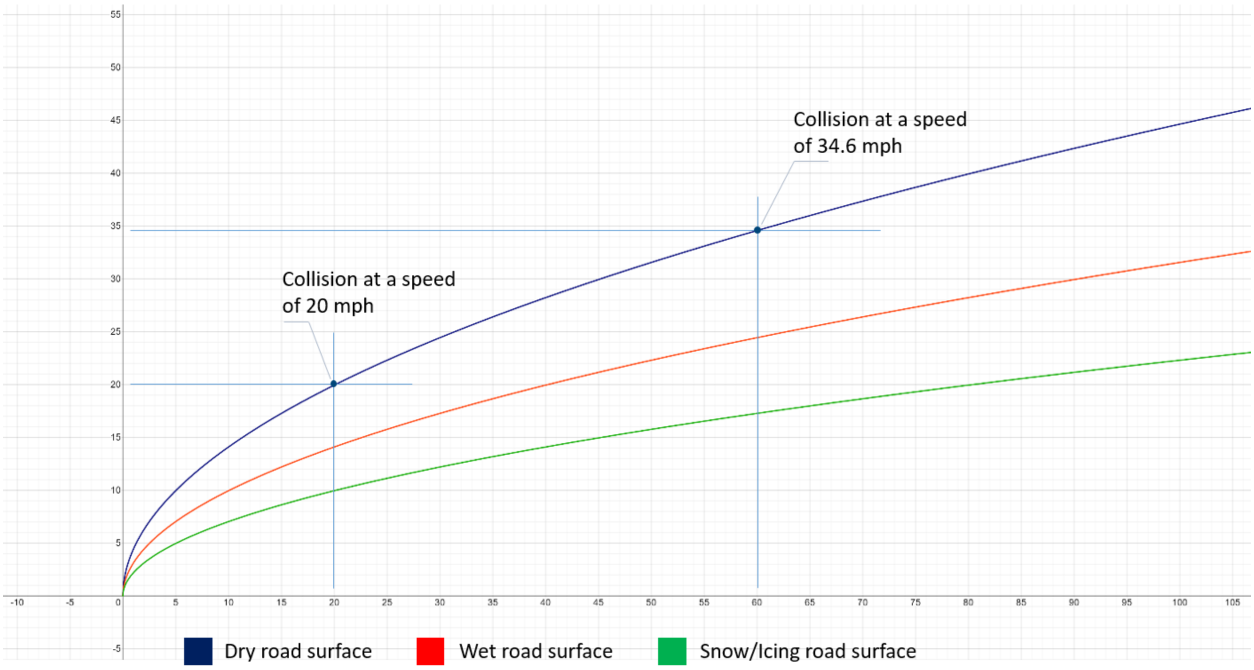
Speed of vehicle, mph	Road Surface	Thinking Distance, ft.	**Stopping Distance, ft.**
30	Dry	123.2	**177.1**
	Wet		**222.2**
	Snow/Ice		**312.5**
70	Dry	287.5	**553.6**
	Wet		**799.2**
	Snow/Ice		**1290.5**

The obtained results show that when a vehicle is moving at a speed of 30 mph, the presence of a dynamic pedestrian escorting system on an unregulated pedestrian crosswalk makes it possible to reduce the stopping distance by 13.2 ft (4 m) in comparison with a crossing with standard street lighting and by 22 ft (6.7 m) in comparison with an unlit crosswalk. When the vehicle is moving at a speed of 70 mph, these values will be 30.8 ft (9.4 m) and 51.4 ft (15.7 m), respectively.

In case of emergency braking, the dependence of the speed at the start of the braking and the braking distance will be as follows:

$$v = \sqrt{\frac{2g\varphi S}{k}}.$$

Consider the graphics of this function for cases of dry, wet, and snow-covered / icy road surfaces.

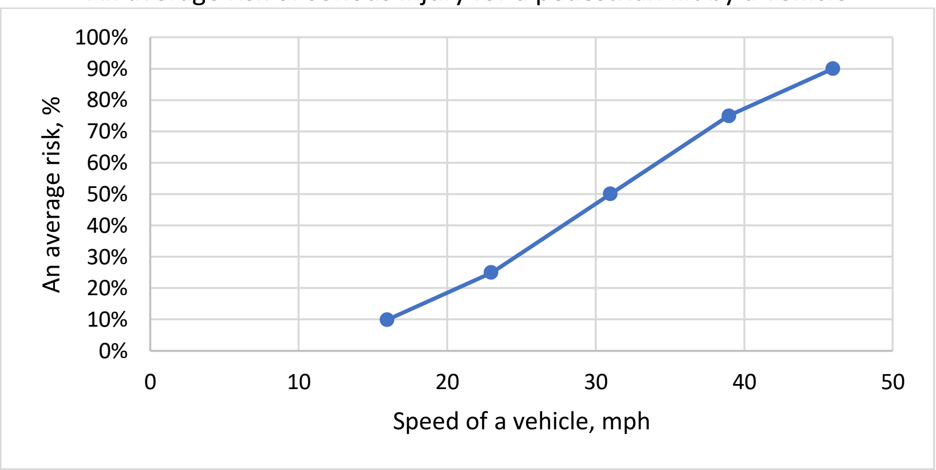


On three graphics the same braking distance corresponds to three different speeds at the time of braking. The highest speed value will be in the case of driving on a dry road. In this regard, the option of a dry asphalt concrete surface is further considered.

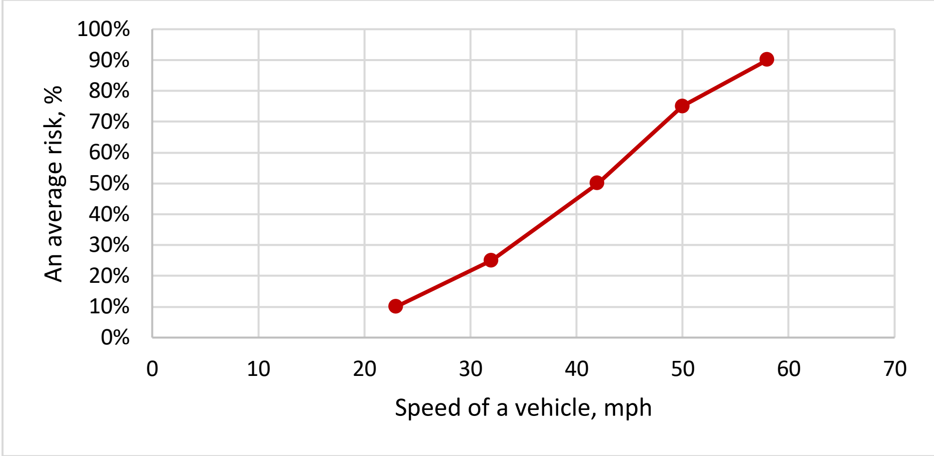
Let's analyze the situation when the vehicle does not have time to stop in front of the pedestrian. If the auto's stopping distance ends at 20 ft. (6.1 m) further than the actual location of the pedestrian, this means a collision at a speed of 20 mph (32 km/h). At the end of the braking distance at 60 ft (18.5 m) beyond the pedestrian's location, a crash will occur at a speed of about 35 mph (56 km/h).

According to research[iii] [iv], the average risk of severe injury for a pedestrian struck by a vehicle reaches 10% at an impact speed of 16 mph, 25% at 23 mph, 50% at 31 mph, 75% at 39 mph, and 90% at 46 mph. The average risk of death for a pedestrian reaches 10% at an impact speed of 23 mph, 25% at 32 mph, 50% at 42 mph, 75% at 50 mph, and 90% at 58 mph.

An average risk of serious injury for a pedestrian hit by a vehicle



An average risk of death for a pedestrian hit by a vehicle



It is obvious that reducing the stopping distance of the vehicle allows either to completely avoid a collision with a pedestrian or reduce the vehicle's speed at which the collision occurs. In the second case, the survival rate of pedestrians in an accident increases significantly.

Conclusion

The obtained results confirm the hypothesis that in the dark, the driver's reaction time to a pedestrian on an unregulated crosswalk equipped with a dynamic light escorting system is lower than the reaction time to a pedestrian on a crosswalk with standard street lighting or on an unlit pedestrian crossing.

The use of dynamic light tracking systems at an unregulated pedestrian crosswalk can significantly increase the safety of pedestrians, reduce the number of accidents involving them, as well as increase the survival rate in the remaining part of such accidents.

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