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中文摘要

過去道路安全相關研究多著重於高事故風險之情境分析，然而透過高事故風險情境之擷取僅能呈現事故外顯的結果，無法探知其成因；因此，為更深入探討事故之肇因與原型，基於前期研究對於事故鏈概念與駕駛人行為特性之了解，本研究以駕駛人心智程序出發，探討駕駛人在面對駕駛作業與環境中各個影響行車安全之威脅時，其認知心理層面之反應，藉以更深入剖析事故發生成因與原貌，並進一步探討駕駛人於事故過程中所扮演之角色。於第一年期，本研究探討行車過程中，人、車、路、環境等四大環節與心智負荷量之互動，以解構心智負荷的產生與其對行車安全之影響，並建構駕駛心智負荷模式。本年度則針對心智負荷模式當中的工作需求更深入探討駕駛人在面對多重平行工作時，如何在有限的心智資源下，將其注意力分配至各個駕駛活動上。收集完整資訊為影響安全駕駛的重要因素，當注意力分配之機制失效時則會導致無法完整收集資訊，並造成事故風險的增加，是故，在探討駕駛人是否正確分配其注意力之前，必須先界定駕駛注意力分配的策略與模式，了解駕駛人在面對駕駛環境內眾多資訊源時其視覺焦點的移轉模式。本研究提出注意力分配模式之概念架構，並且將影響各個行車安全威脅注意力需求之因素歸納為認知風險、定向反應與行車資訊收集三大類，後續將繼續進行實驗資料收集與參數校估之工作；透過模式之構建，未來研究可以此平台探討駕駛人在不同環境條件下的注意力分配策略，並了解給予行車資訊對於駕駛安全與注意力分配的淨影響。

英文摘要

The increasing number of roadway accidents has led researchers to focus on accident-prone scenarios to get a clearer picture of the accident occurrences through accident chain. However, such scenarios explain the conditions and mechanism of a collision rather than its true cause. Based on previous research on accident chain and driving behavior, this research further analyze individual drivers’ mental process for better explore the nature and causality of accidents. In the first stage of this research, the framework of mental workload was constructed. The contributions of human, vehicle, roadway geometry and environment to mental workload were also discussed. In this stage, issue of task demand in mental workload analysis is addressed to clarify drivers’ mental behavior while facing multiple and parallel activities. Noting that driving is a continuous process of information collection, drivers need to allocate attention to different objects to perceive useful information. Malfunction of attention allocation can lead to incomplete information perception and higher accident risk. Modeling drivers’ attention allocation in different conditions is a major step in identifying the external information drivers perceive and react to. The purpose of this research is to propose the framework of attention allocation model and address the critical contributing factors. Three major types of contributors, perceived risk, orientation reaction and driving information perception, are proposed to construct the attention allocation model. In the next stage of research, field data collection and parameter calibration will be conducted. On the basis of this model, attention allocation policy under different condition can be clarified. Moreover, the net safety impact of providing information to drivers can be obtained.

壹、研究緣起

1. 事故分析

道路交通安全管理一直是交通運輸界關注的焦點之一，為進一步了解事故之成因，並研擬策略以對症下藥，透過資料分析技術之演進與總體性資料之應用，近年來許多研究針對人 (Chang and Yeh，2007；Clarke *et al.*，1998)、車 (Albertsson，2005；Chang and Yeh，2006)、路 (Chin and Quddus，2003；Wang and Abdel-Aty，2003)、環境 (Eisenberg，2004；Keay and Simmonds，2006) 等事故風險因素進行分析，探討上述因素對特定事故型態造成之影響。然而此等研究雖能提供重要訊息供事故防範之參考，然而由於尚未完全建立整體系統分析之能力，同時對於事故分析亦侷限於最接近事故發生之外顯表象因素，使得肇事因素之發掘工作往往只能達到表層發現一些不安全的行為。

有鑑於此，近年研究跳脫表面所見之風險因素，試圖導入事故鏈之概念，將遠端因素納入分析 (Verschuur and Hurts，2008；Wong and Chung，2007a；2007b；2008)。事故鏈之概念不僅是分析道路幾何等變數建構易肇事路段，同時亦納入諸如駕駛者類型、旅次目的等行前變數，了解不同類型駕駛人在特定環境條件下的事故風險，並且藉此寶貴資訊建立高風險事故情境。事故鏈之建立雖有助於進一步解構事故並釐清成因，然而此類型研究僅能解釋駕駛人在何種情境下具有較高的事故風險，以及在特定變數組合下可能導致事故類型或嚴重度的差異，然而事故鏈卻仍無法解釋為何事故會發生在該情境下，事實上，在所有行經易肇事路段或高風險駕駛情境的車輛當中，僅有極少數車輛發生事故，為更進一步探討駕駛人於此等情境當中的行為特性，相關研究必須更進一步探討駕駛人於事故鏈當中所扮演之角色。

因此，前期計畫以駕駛人自我報告方式收集駕駛人行為特性，發現越容易分心以及越不容易緊張的駕駛人，越常發生超速被取締；此外，駕駛經驗越久、結過婚、有小孩以及開車通勤的人，較不常出現分心、急躁、不警覺、解離或緊張等駕駛行為。鑒於駕駛人行為對安全之關鍵性影響，針對年輕機車騎士建構高風險駕駛行為模式，結合計劃行為理論 (Theory of Planned Behavior，TPB) 與風險平衡理論 (Risk Homeostasis Theory，RHT)，了解駕駛人於決策過程中所思考的環節與環節間的互動，將有助於更進一步釐清事故之原貌；研究結果顯示，年輕機車騎士並非同質群體，不同類型的駕駛人可能採取截然不同的駕駛行為，例如具有良好技術、自信且對於現代駕駛文化十分了解的駕駛人仍會有高頻率的高風險駕駛行為，此等結果提供了安全教育以及智慧型運輸安全系統發展策略上重要之參考 (Wong *et al.*，2010；Wong *et al.*，2011)。

結合前述兩階段之研究，駕駛人行為特性可幫助補足事故鏈之不足，透過不同族群駕駛人之行為特性研究，事故鏈更能呈現何種駕駛人傾向在高風險事故情境之下採取較具風險之駕駛行為；然而同樣的問題卻仍然存在，並非所有採取高風險駕駛行為的駕駛人，在高風險事故情境當中即一定會發生事故，換言之，透過事故情境與駕駛人外顯駕駛行為所建構之高風險事故情境仍無法完整呈現事故全貌，為補足兩者之間的失落環節，本三年期計畫「即時安全資訊系統之建構、分析與應用」將以駕駛人心智程序出發，探討駕駛人在面對駕駛作業與環境中各個影響行車安全之威脅時，其認知心理層面之反應，了解在每個行車決策過程駕駛人必須投注之心智資源，由個體心智模式之觀點進行事故分析可更深入剖析事故發生成因與原貌，透過心智因素可進一步探討駕駛人以及其對情境認知於事故過程中所扮演之角色。

於第一年期，本研究探討行車過程中，人、車、路、環境等四大環節與心智負荷量之互動，以解構心智負荷的產生與其對行車安全之影響，並建構駕駛心智負荷模式。心智負荷可被定義為在給定一能力水準之下，為了完成特定目標與工作所必須消耗的資源 (Hart and Staveland，1988)，心智負荷的形成主要受到兩個關鍵因素的影響─工作需求與心智能力，透過兩環節之互動可得駕駛人在不同環境下的心智負荷程度；於駕駛過程當中，面對各種不同的駕駛環境、行車安全威脅與行車資訊，駕駛人必須承受不同程度的心智負荷，然而心智負荷並非一定會造成道路安全之負面影響，駕駛人一般會傾向維持心智負荷於最佳的水準 (Hill and Boyle，2007；Horberry *et al.*，2006a；2006b；Recarte and Nunes，2002；Oron-Gilad *et al.*，2008)，當無法維持最佳化水準時則必須進行修正調整，而當此一修正調整機制失效時，駕駛即有可能發生事故風險。

於前期對心智負荷之探討當中，駕駛工作需求為一關鍵議題；駕駛人於行車過程當中必須同時面對多重的平行工作，不同的工作其特性的差異皆會造成不同程度的駕駛工作需求。過去研究多透過單一變數的改變來反應駕駛工作需求，例如行車速度、對話複雜度等，此等方式雖能深入探討個別因素對心智負荷之影響，但是因為不同駕駛工作項目不可相加，導致無法反映多重平行駕駛工作之特性。因此，將進一步以注意力分配為題，了解駕駛人於行車過程中分配注意力與收集資訊之機制，考量注意力須被分配到每一個駕駛人所關心並執行的駕駛活動上，分配注意力可被視為分配其心智資源，換言之，在面對各種行車環境與安全威脅下，每一物體或車輛所帶來之駕駛注意力需求可被視為其工作需求。透過注意力分配之探討，本研究可進一步分析在眾多行車資訊之影響下，何種行車資訊可幫助駕駛人妥善分配注意力，並在下一年度以此為基礎，建構一整合性的行車資訊系統。

2. 駕駛注意力分配

過去多數研究皆顯示人為因素為道路交通事故最重要的影響因素 (Chen *et al.*，2005；Horberry *et al.*，2006a；2006b；Dahlen *et al.*，2005；FMCSA，2009；Nabatilan，2007；Reed-Jones *et al.*，2008；Ulleberg and Rundmo，2003)，以我國為例，2008 年所有道路交通死亡事故當中，高達 85%導因於諸如違規駕駛、未依規定讓車、酒後駕車、未保持安全車距或危險駕駛行為等人為因素，在所有的人為相關死亡事故當中，「未注意車前狀況」佔了其中的 22%，為造成道路交通人為相關死亡事故的主要原因之一 (交通部統計處，2009)。美國相關研究同樣顯示，分心 (Distraction) 與不注意 (Inattention) 為人為相關道路事故的最主要兩個肇事成因 (FMCSA，2009)。注意力的錯誤配置 (Attention misallocation) 與不注意為注意力分配機制的失效，駕駛人若無法善用其注意力分配機制以觀察道路車流狀況，並收集影響行車安全之資訊，則會導致事故風險的增加。結合事故鏈概念可知，注意力分配失效為連結「高事故風險駕駛情境」以及「事故發生」的重要環節，雖然駕駛於易肇事路段之事故風險較其他路段高，然而若駕駛人得以妥善分配注意力，即便是行駛於高風險路段仍能有效降低事故風險，反之，若在高事故風險駕駛情境行車時產生注意力錯誤分配或不注意狀況則會顯著增加事故發生之機率。

駕駛過程當中，駕駛人必須持續收集資訊、處理資訊、理解資訊、決策與執行操作，其中，收集完整資訊為影響安全駕駛的重要因素。駕駛相關資訊包含車速、道路其他車輛動態、道路幾何、路徑資訊、標示標誌與號誌等，若無法完整收集所須之相關資訊，或是收集錯誤與無用的資訊皆會導致駕駛人對於駕駛環境的認知不足，基於不完整或錯誤的資訊，駕駛人可能誤判行車狀態並忽略造成衝突危險的潛在安全威脅，進而做出錯誤的決策導致事故發生。為維持車輛行駛於安全軌跡之上，面對車外的多重資訊源，駕駛人必須將注意力依序移轉至相關位置與物體上，觀察安全威脅動態，藉以收集行車安全的相關資訊。

注意力可被定義為具有指向性與集中性的意識 (Zomeren and Brouwer，1994)，注意力分配的機制與策略為影響駕駛人是否能夠有效率收集安全駕駛相關完整資訊的重要環節。Kahnement (1973) 於其注意力理論當中提及，人們的心智資源並非毫無限制，注意力分配策略 (Allocation policy) 目的為在有限心智資源之下，透過注意力分配將該心智資源有效率的分配至各個外界刺激，以接受相關資訊；注意力分配策略係基於各個刺激之注意力需求 (Attention demand)，以駕駛人之觀點而言，每位駕駛人心中皆有一個處理器內含注意力分配策略，該處理器負責接收外界環境的刺激，判斷各個資訊源的注意力需求，接著依據其需求將注意力分配至對應之活動，需求越高者所吸引的注意力也越高，當駕駛人分配注意力的能力退化時，其偵測道路駕駛安全威脅的能力也隨之退化 (Creaser *et al.*，2007；de Waard *et al.*，2009；Laberge *et al.*，2006；Marmeleira *et al.*，2009)。

駕駛分心代表駕駛人將注意力自駕駛工作移轉至其他物體、資訊源或事件所產生的刺激上 (FMCSA，2009)，為注意力錯誤配置的重要表徵之一，駕駛的主

要作業 (Primary task) 包含技術性 (Technical task) 的加減速、行車方向調整等，以及非技術性 (Non-technical task) 的觀察周圍車流、注意車速、收集外在訊息、判斷決策等，技術性作業必須仰賴由非技術性作業所得資訊，當駕駛人將注意力自上述非技術性主要作業移轉至其他次要作業，例如手機通訊、聽音樂或聊天等，會增加駕駛人面對外界刺激的反應時間，進而增加事故風險 (Neyens and Boyle，2007)。此外，透過車內資訊系統 (In-vehicle information system，IVIS) 提供資訊予駕駛人之本意為幫助駕駛人取得駕駛相關資訊，以降低不確定性以及協助事先規劃心智資源與注意力分配，然而錯誤的資訊，或是錯誤的提供方式、地點、時間、內容，反而會製造負面效應，使駕駛人必須分心接收資訊並判斷其關鍵性，甚或是將注意力錯誤分配至無用資訊源上，導致駕駛人錯失真正重要的資訊 (Liang *et al.*，2007；Vashitz *et al.*，2008；Wong and Chung，2007a)。

探討視覺注意力分配策略之研究可分為兩大類，第一類型之研究為透過總體性資料之收集，分析駕駛人在特定狀態、情境下，將注意力 (目光焦點) 集中在特定物體、區域的比例 (Levin *et al.*，2009；Nabatilan，2007)。透過眼球瞳孔追蹤，相關研究發現駕駛人的目光焦點 (Eyesight fixation) 在大多數的狀態下都是集中在車輛前方，以避免前進的同時與前車發生追撞，然而除此之外，仍有部份注意力被分配到其他地方，此小部份的注意力分配狀況取決於當下駕駛人欲採取的駕駛行為意向以及事件特性而定，例如當駕駛人接近路口要轉彎時，會主動將其注意力移轉至垂直方向處。除了總體性注意力分配之相關研究外，Lim *et al.* (2004) 提出個體視覺注意力模式，該研究納入道路上其他車輛的視覺強度變數 (例如車輛大小、遮蔽程度、顏色對比、狀態變化程度)、操作特性 (例如垂直速度、水平速度)、駕駛人特性變數 (例如敏銳度) 以及其他主觀變數 (例如車輛的重要度、獨特性、吸引力) 藉以評估注意力需求值 (Attention demand value，ADV)，唯有注意力需求值最高的車輛才會被納入短期記憶並加以處理。此研究雖可反映駕駛人在駕駛過程中的即時注意力移轉，但其中仍有部份議題需要進一步釐清；首先，該研究認為僅有注意力需求最高的車輛才會被納入短期記憶，其餘車輛不會被駕駛的心智所處理，然而僅納入注意力需求最高的單一個體無法反映駕駛人得以在視線所及範圍內辨識、收集以及處理多重資訊，駕駛人會在大部分時間將注意力分配至需求最高的車輛，然而需求較低的車輛仍然會吸引到駕駛人的目光；此外，該研究僅將注意力焦點集中在行駛於道路上的其他車輛，然而為了隨時保持情境察覺能力，在道路上沒有車輛佔據的區域也會吸引注意力的投入，藉以隨時觀察該區域會不會出現可能影響行車安全的威脅；再者，為選取注意力需求最高的車輛，系統必須掃描駕駛環境中的所有個體，方能評估其注意力需求並選取其中最高者，此一流程已隱含注意力分配之課題，駕駛人會依其分配策略選取下一個欲觀察的對象，其觀察次序、停留時間皆受到駕駛人潛意識中的處理器所影響，依據環境條件、意向、事件的差異，部分車輛或區域可能會連續被觀察數次，同時，亦有部分車輛或區域不會被駕駛人所在意，此一注意力分配的策略即為本研究關注之核心議題。

注意力分配機制的失效為造成道路交通事故的關鍵環節，如同前述，駕駛由連續不斷的資訊接收、處理、決策與執行所組成，於行車過程當中，所有車輛每一分秒都在變化其狀態，即使只是瞬間的失神或是分心，導致注意力錯誤分配而無法觀察到安全威脅動態的變化，駕駛人於該瞬間即無法完成完整資訊的收集，而在不完整資訊下進行的行車操作將會造成操作失誤的可能性，進而危及安全。在探討駕駛人是否正確分配其注意力之前，必須先界定駕駛注意力分配的策略與模式，了解駕駛人在面對駕駛環境內眾多資訊源時其視覺焦點的移轉模式。為模化駕駛人注意力焦點的選擇行為，本研究透過個體選擇模式 (Discrete choice model) 將重要影響因素納入，藉以探討在不同駕駛環境、安全威脅動態等條件下，選擇各個安全威脅或區域作為注意力焦點以收集資訊的機率。透過本模式之建立，後續研究得藉由此工具探討駕駛人在面對各種不同的資訊提供時，能否降低其分心狀態，並增加其對駕駛狀況的掌握程度，以提升行車安全。

於本年期研究中，為探討駕駛面對多重安全威脅與平行駕駛資訊時，分配其心智與注意力資源的機制與程序，本研究提出駕駛注意力分配模式，並定義模式決策變數與操作過程，以呈現駕駛不斷進行資料收集、處理與行車操作執行的過程，作為後續探討即時安全資訊於道路安全之應用。

貳、研究架構

1. 分割注意力模式

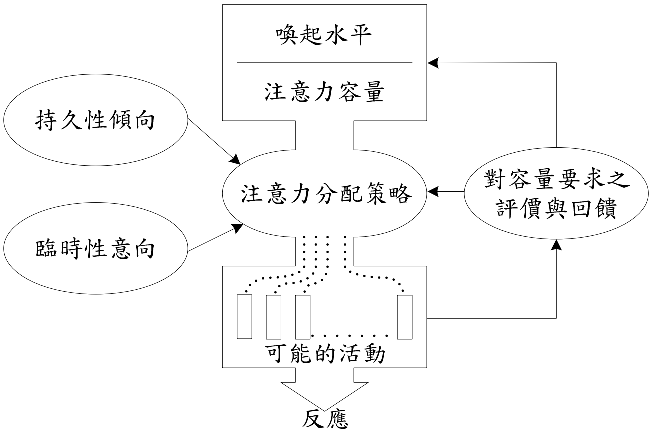
分割注意力模式由 Kahnement (1973) 所提出，不同於過去單一通道 (Single channel) 之過濾器模式 (Broadbent，1958) 與衰退模式 (Treisman，1960)，分割注意力模式認為在給定的注意力容量 (Attention capacity) 之下，不同的個體、刺激或活動得以同時被注意與執行，同時心智資源亦可被分配到多個目標上以供人們收集外界資訊並激發相關反應，圖 1 為分割注意力模式之架構。分割注意力模式主要由四大假設所組成：

(1) 一個人的心智容量是有限的，但其容量限制並非固定不變，而是受到喚起水平 (Arousal level) 影響，不同的生心理特性 (例如精神狀態、疲勞、緊張等) 會影響人們的喚起水平，進而影響可供使用之心智容量。

(2) 每個物體、刺激或活動被分配到的注意力資源 (或心智資源)取決於該目標的需求水平 (Level of demand)，需求越高者，人們會傾向分配較多注意力。

(3) 注意力具有可分割的特性，人們得以將注意力依需求等級分割至不同目標上。

(4) 注意力的分配為可選擇且可控制，每個人都具有注意力分配策略，藉以決定分配注意力資源之機制。



資料來源: Kahnement (1973)

圖 1 分割注意力模式

注意力分配策略為分割注意力模式之核心環節，Kahnement (1973) 指出該策略之形成主要受到四種因素所控制，包含喚起水平 (Arousal level)、持久性傾向 (Enduring disposition)、瞬時性意向 (Momentary intention) 與對容量要求之評價 (Evaluation of demands on capacity)。喚起水平為被包含生理特性、疲勞、緊張程序、警戒等因素所激發出的最大注意力容量；喚起水平與作業執行成果兩者間存在一倒 U 字型關係，人們在執行工作時必須維持最佳之喚起水準方能產生最佳的注意分割，過低的喚起水平會造成注意力容量不足，導致應被注意到的物體或刺激無法分配足夠之注意力，反之，過高的喚起水平會降低人們判別注意力需求的能力，導致無法有效區分重要的物體與可被忽略的外界刺激。持久性傾向反映外界環境的特性以及變化，例如前方車輛突然減速或鄰近車道車輛閃方向燈等，受到不同的傾向之刺激，駕駛人得以被動控制注意力之分配，藉以持續觀察環境之組成與改變。瞬時性意向則是反映駕駛人主動性的注意力控制，此意向是由當時情境所要求或是引起的注意傾向，例如駕駛人被要求尋找路旁的店家或是使用車內的資訊系統等。在受到上述因素影響而對外界刺激進行注意力分配，並針對刺激加以反應後，人們針對需求、注意力與容量現況加以評估，若現有之容量不足以完成所要求之作業時，則透過更加專心或警戒增加喚起水平，並且重新調整分配策略，以投注更多資源於重要的活動上。

駕駛過程當中，駕駛人必須持續性的投入注意力以觀察路上與路旁的狀況，藉以取得安全駕駛的完整資訊 (Complete information)，例如當一名駕駛欲變換車道時，完整資訊包含鄰近車道前後方的車流，以及目前行駛車道的前方車輛，若僅將注意力集中在鄰近車道上，駕駛人無法得知前方車輛是否有改變其車速，當前方車輛減速並縮短兩車間距時，即有可能導致駕駛人反應時間不足，無法做出正確之避讓操作，進而導至追撞事故的發生。上述事故情境在事故鏈當中僅能呈

現一個在變換車道過程當中發生的追撞事故，然而其關鍵點在於駕駛人是否能夠妥善分配其注意力，若駕駛人在分割其注意力的過程當中，無法分配足夠注意力在需要的目標上，亦或是分配至錯誤的活動上，將導致不完整的資訊接收，進而造成事故發生。

注意力分配失效主要可以分為兩種類型：不注意 (Inattention)、注意力錯誤配置 (Attention misallocation)。過去研究顯示，高齡駕駛人常面臨情境察覺能力的退化現象 (Clarke *et al.*，1998；Creaser *et al.*，2007；de Waard *et al.*，2009；Laberge *et al.*，2006；Marmeleira *et al.*，2009)，造成駕駛人難以確實接受外界資訊或誤判狀況，即使駕駛人能夠了解哪些車輛或交通可能造成安全威脅，必須加以注意，但是其資訊接受處理能力退化導致其雖然注意了，但卻無法完整接收應處理之訊息；反之，新進駕駛人常面臨到的問題是注意力錯誤配置，即使新進駕駛人可以妥善處理所接受之刺激並轉換成可用之訊息，然而由於經驗不足，注意力可能被分配到不正確的物體上，導致無用的訊息接收，過去研究顯示較具經驗的駕駛人對於注意力分配的策略較為正確，因此，此類駕駛人方能做出正確的決策 (Nabatilan，2007；Underwood *et al.*，2002)，相較之下，新進駕駛人有較高的機會無法做出正確判斷，將注意力投注在正確的物體上，導致注意力分配的失效，造成無用資訊的接收處理，並錯失真正重要的資訊 (Drummond，1989)。

近年來，許多研究皆採實驗方式，藉由分心與次要作業測試探討駕駛人注意力分配之課題，然而鮮少針對駕駛注意力分配策略進行數量化之研究，探討駕駛人在不同狀況下，採取分配注意力之機制，分析在不同等級的分心水準之下，對安全駕駛產生之衝擊。為進一步探討駕駛人在面對多重安全威脅以及資訊源之下，如何妥善分配其注意力，同時探討完整資訊在不同交通狀況下之意義與內涵，本研究提出駕駛人注意力分配模式，藉由心智層面之探討分析，期望能夠進一步釐清事故之原貌。

2. 駕駛注意力分配

注意力分配模式於駕駛之應用包含兩層面之意義，首先，駕駛人在每一次的注視可以透過視線焦點與餘光 (Peripheral vision) 同時接收平行資訊，然而駕駛人所面對之安全威脅來自環繞 360 度的駕駛環境，每一次的注視僅能提供部份的資訊，無法同時接收並處理所有可能威脅到駕駛安全的物體；因此，為了收集完整資訊並作出正確之決策與行車操作，駕駛人必須不斷轉移視線與注意力以達到完整資訊的收集。上述的流程當中，駕駛人在每次的視線轉移過程當中都必須要選擇下一個視線的焦點，圖 2 為探討駕駛人注意力移轉的過程，其中可分為四階段進行探討，1) 駕駛環境與短期記憶狀態辨識、2) 注意力焦點選擇、3) 資訊接收與 4) 短期記憶更新與回饋。

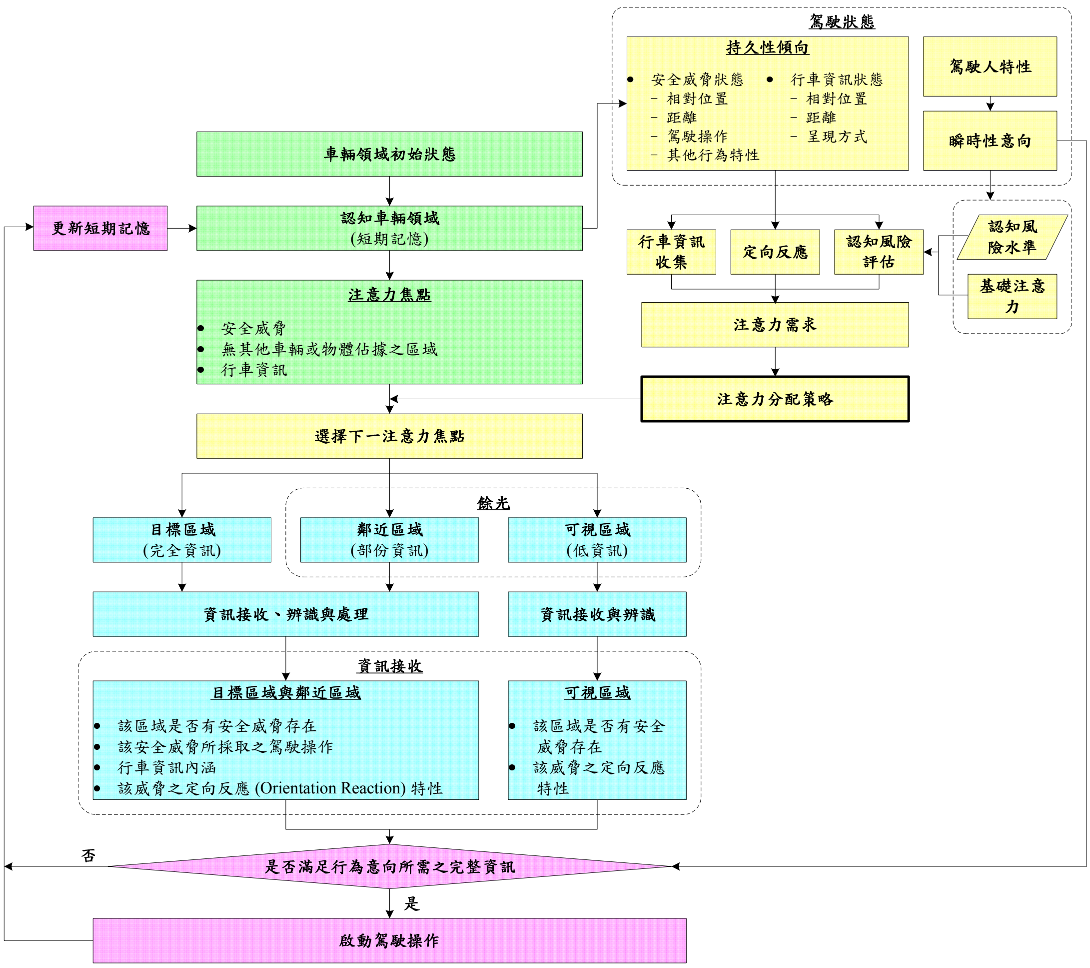


圖 2 駕駛注意力分配流程

駕駛注意力分配的第一階段為駕駛環境與短期記憶狀態辨識，於此階段，駕駛人得以確認在所處環境當中，各個潛在注意力焦點 (Attentive focus) 的位置、狀態與特性。駕駛的過程當中，駕駛人將車輛領域 (Drivers' vehicle domain) 當中，各個車輛、區域等注意力焦點之狀態 (例如各個車輛的所處位置、距離、操作等特性) 存在短期記憶當中，隨時提取資訊以供決策之用。短期記憶當中所儲存之資訊皆是由駕駛人在前期所收集並更新，然而行駛在真實環境的過程中，各個車輛皆會持續改變其狀態，例如加減速、變換車道等，上述改變在駕駛人將注意力移轉至該處並接受到相關資訊前並不會被更新，因此短期記憶所提供的資料與現實狀態可能有時間上的落差，然而駕駛人的注意力分配係依據其所認知到的駕駛環境而定，因此，本研究將此一短期記憶命名為「認知車輛領域」，藉以與真實車輛領域的交通狀況加以區分。短期記憶內可儲存三種注意力焦點的相關狀態，包含安全威脅、無車輛占據之道路區域與行車資訊，安全威脅包含車輛、固定物、工作區等位於車輛領域內的物體；除了將注意力投注在上述安全威脅之外，駕駛者對於無車輛占據的道路區域仍應維持一定程度的注意力與警覺，持續觀察該區域是否出現可能影響安全之車輛或其他物體；第三類則是行車資訊，駕駛人於行駛過程當中，除了接受其他車輛所產生的資訊外，仍會透過諸如標誌或

車內系統取得相關行車資訊，例如該路段限速、附近車禍事故地點、路徑導引等。在眾多類別的注意力焦點當中，當駕駛人依據注意力分配策略選擇其一，並得以觀察所選注意力焦點並獲得相關的資訊。

注意力分配的過程當中，分配策略為最重要之關鍵環節，該策略決定駕駛人選擇特定物體或區域作為注意力焦點並加以觀察的機制，本研究透過駕駛人選擇特定注意力焦點的機率來呈現注意力分配策略。如圖 2，注意力分配策略係基於注意力需求之評估，注意力需求的形成必須透過駕駛狀態與認知風險水準兩資料之輸入。駕駛狀態由持久性傾向與瞬時性意向所形成，於行車過程中，駕駛人自短期記憶中提取上述兩類駕駛狀態相關資訊，藉以評估當下各安全威脅之風險等級；持久性傾向反映在駕駛環境當中各個物體的狀態，包含其他車輛 (安全威脅) 的動態與行車資訊的狀態，瞬時性意向則反映不同事件下駕駛人必須執行的操作，或是駕駛人本身意欲採取之行為。注意力分配策略的第二類輸入資料為駕駛人的認知風險水準，面對駕駛環境當中的各個安全威脅，駕駛人採取各種不同駕駛操作皆會產生不同狀態的車輛領域，並且製造來自不同方向、位置的行車軌跡衝突，因此，各個安全威脅對駕駛人皆會造成程度相異的風險水準，於本研究所提之注意力分配模式當中，認知風險水準被視為影響注意力需求之重要變數。此外，並非僅有已存在的安全威脅才會被駕駛人所關切，駕駛人對於並無任何物體佔據的道路空間仍會維持一基礎注意力 (Spare attention)，以維持情境察覺之能力；基礎注意力的投入受到駕駛操作本身特性及駕駛人認知風險水準所影響，一般而言，若駕駛維持行駛在同一車道，注意力則會集中在前方區域，然而若欲採取變換車道時，則會提高鄰近車道前後方之基礎注意力 (Levin *et al.*，2009；Nabatilan，2007)，換言之，基礎注意力仍會受到認知風險水準影響，當駕駛人預期該處若出現其他車輛會造成較大之風險時，為維持情境察覺能力並在安全威脅出現得以提早因應，駕駛人會傾向投注較高程度的基礎注意力。基於上述駕駛狀態、認知風險水準與基礎風險水準，影響注意力需求之因素可歸納為行車資訊收集、定向反應與認知風險評估，此一核心環節將於第四章深入討論。

在依據注意力分配策略選擇一區域或物體作為本階段之注意力焦點後，駕駛人得以透過視覺接收該區域所產生之資訊，透過視覺接收資訊可分為四種等級，第一級為駕駛人將中央視野移轉至所選注意力焦點的目標區域，在人們的可用視野當中 (Useful field of view，UFOV)，透過中央視野方能接收完全資訊 (Full information)，駕駛人得以據此判斷該區域是否有安全威脅存在，監控該威脅的移動，並且預測未來軌跡；第二級的視覺接收為所選注意力焦點的鄰近區域，雖然該區域僅能透過駕駛人的周圍視野所觀察，所得資訊量不如由中央視野觀察的目標區域，然而由於較接近目標區域，雖僅能收集部份資訊量，但仍足以讓駕駛人做安全威脅的觀察與監控；第三級的視覺接收為可視區域，該區域為周圍視野之邊緣，可提供之資訊量極為有限，駕駛人僅能確認該區域是否有其他物體，然而無法更進一步觀察該物體的動態或是其他特性；第四級的視覺接收為不可視區

域，受限於視野的廣度，駕駛人無法在同一瞬間觀察環繞駕駛車輛的所有區域，例如當駕駛人將視線集中在車前狀態時，車後狀態無法被視線所及，位於不可視區域之資訊，唯有當駕駛人在下一時階進行注意力焦點選擇時，將視線移轉至該處後方能被觀察。

駕駛注意力分配流程的最後一階段為短期記憶更新與回饋，當駕駛人完成每一輪的注意力焦點選擇，並接收該區域或安全威脅各項屬性的資訊後，駕駛人會將該資訊回饋至短期記憶，並將與前期相異處進行更新。依據更新後的短期記憶，駕駛人必須判斷所收集之資訊是否滿足行為意向所要求的完整資訊，完整資訊之內涵取決於行為意向與事件特性，若已收集到完整資訊，駕駛人將啟動駕駛操作並進入下一階段的注意力分配，若尚未完整收集相關資訊，駕駛人必須再次進行注意力分配，藉以補齊不足之資訊。

參、安全威脅與車輛領域

在行車過程中，駕駛人必須持續移轉其注意力以選擇目標、觀察並更新其短期記憶，為探討駕駛人選擇注意力焦點之機制與策略，必須先了解各個安全威脅的特性與其所對應之注意力需求，本章提出車輛領域與認知風險水準之概念，藉以將安全威脅所在位置、距離與行車操作簡化並歸類為數種類別，並探討不同屬性的安全威脅產生之風險等級與注意力需求。

1. 車輛領域

車輛領域為在距離駕駛人特定距離內的虛擬空間，於行車過程當中，車輛領域內存在著可能與駕駛人產生互動之物體，包含車輛、行人、路緣、固定物等，以及所有為達成安全駕駛目標所必須要接收處理的資訊。此外，車輛領域可反映駕駛人在情境察覺、風險辨識與決策特性上的差異，為避免與其他安全威脅產生衝突，駕駛人必須將其注意力分配至車輛領域中的各個角落，藉以收集相關資訊並進行處理與決策。提出車輛領域概念之目的在於簡化安全威脅與駕駛人之間複雜的互動關係，藉由設立三個具有不同意義的虛擬空間，探討位處不同領域的安全威脅對行車安全之衝擊程度差異，以及對駕駛人注意力分配的影響，藉以幫助研究者確認駕駛人在面對不同屬性的安全威脅時，在心智層面上激發的反應，以及後續可能採取的行為。

圖 3 為車輛領域之概念示意圖，車輛領域又可分為三種不同之子領域：關鍵領域 (Critical domain)、觸發反應領域 (Reaction domain)、認知領域 (Perception domain)。關鍵領域為避免車禍發生之安全臨界範圍，任何物體 (包含車輛、行

人、靜止物以及任何可能影響行車安全之潛在風險) 只要進入此一區域就會造成衝突；認知領域 (Perception domain) 則是代表駕駛人在特定速度、環境條件下的最遠視距；至於反應領域則為物體或資訊進入此一區域，將進一步為駕駛人所反應並處理，換言之，當物體進入此區域時就會增加駕駛人的心智活動，並且產生決策與心智負荷。關鍵領域與反應領域的相對位置為影響心智負荷的重要關鍵，縱使駕駛人得以將注意力分配至車輛領域之任一角落，然而駕駛人遭遇安全威脅之地點較接近事故臨界點 (關鍵領域)，其可以反應之時間極為有限，相關的動作必須在較短的時間內完成，其所對應之風險水準亦較高。

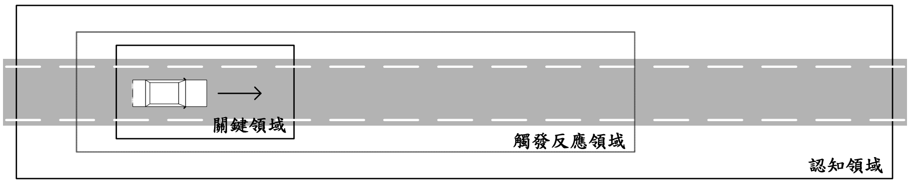


圖 3 車輛領域示意圖

車輛領域可分別由兩層面進行探討：「形狀」與「領域邊界之位置」，以下將針對關鍵領域、反應領域、認知領域三者的定義與衡量方式進行說明，。

(1) 認知領域

認知領域為車輛領域中距駕駛人最遠之子領域，可被視為駕駛人的「可視範圍」，因距離較遠，駕駛人對位於認知領域之安全威脅仍有充裕的時間得以反應。惟有已進入認知領域的物體以及該物體所產生之資訊方能被駕駛人所辨識與接收，位於此領域以外的物體因無法被駕駛人所察覺而不會產生任何有效資訊。當安全威脅位於認知領域且被察覺時，駕駛人會進行評估，確認該安全威脅對自身的影響程度，並預測短期內可能之行駛軌跡；然而由於位處認知領域的安全威脅對行車影響極低，駕駛人通常不會立即對位於該領域內之安全威脅採取技術性行車作業 (Technical task)，例如減速、煞車或變換車道等，於此階段駕駛人多採取非技術性之行車作業 (Non-technical task)，投入注意力資源持續觀察監控其運作。圖 4 為影響認知領域形狀與大小的重要因素。

認知領域之邊界受限於駕駛人在特定速度與環境條件之下的最大視距。生理條件為影響駕駛人最大可視範圍的重要因素之一，過去研究顯示，高齡駕駛人受到生理狀態之影響，其視力與其他年齡層的駕駛人相較之下具有顯著退化現象 (Bayam *et al.*，2005；Clarke *et al.*，1999)，此外，諸如夜盲者、白內障等眼部疾病亦會限制駕駛人在特定狀況下的視野。除此之外，外界環境條件亦會影響駕駛人最大視距，降雨、無路燈、夜晚等因素，以及其他建築物或是道路幾何對視線的遮蔽皆會縮短駕駛人的視野。

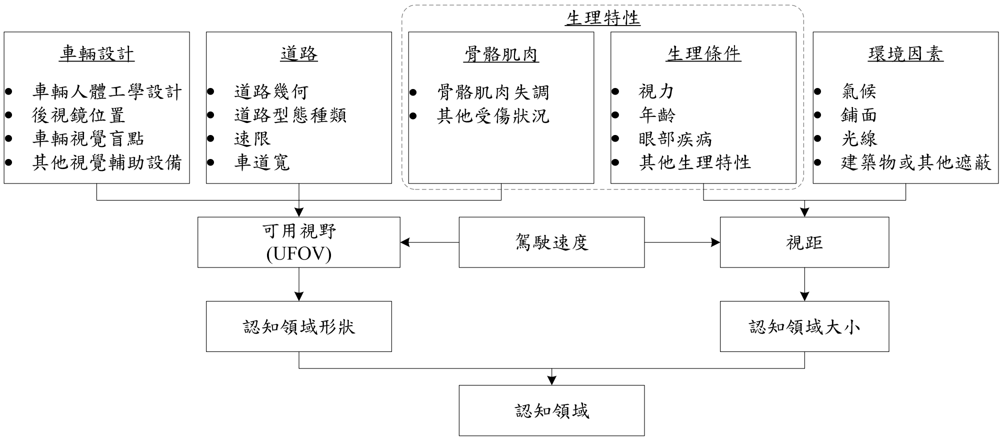


圖 4 認知領域之重要影響因素

認知領域的形狀取決於駕駛人視野的廣度，駕駛人的可視範圍受到生理狀態以及車輛設計的影響。餘光範圍或周圍視野為可用視野的重要屬性之一，人們的視覺接收能力並非侷限於視野的中心區域，眼睛的餘光在駕駛過程當中扮演非常重要的角色，餘光可及範圍越廣，代表駕駛人在每一瞬間的認知領域越大；雖然周圍視野可以超過 100 度以上，然而透過餘光所接收的資訊有限，在可用視野當中，僅有視線的中央區域方能捕捉物體的移動、特性以及其他細節，當行車速度越快時，周圍視野內的物體更難被辨識 (Roess *et al.*，2004)；因此，駕駛人必須依靠轉動眼球或頭部藉以擴展視野，若駕駛人的肌肉骨骼因傷病而無法自由轉動，則可能導致其認知領域的範圍受到限縮。此外，受限於車輛設計與人體構造限制，駕駛人無法直接透過視線的移轉而快速觀察車輛後方之動態，而是必須透過後視鏡加以彌補視線之不足，然而即使有後視鏡之協助，在車輛周圍仍有多處行車盲點無法被駕駛人觀察到。

(2) 關鍵領域

關鍵領域為避免車禍發生之安全臨界範圍，駕駛人於行車過程當中必須固守此一區域，任何物體 (包含車輛、行人、靜止物以及任何可能影響行車安全之威脅) 只要進入關鍵領域即被視為衝突或危險狀況的發生；當安全威脅接近或進入關鍵領域時，駕駛人依然得以將注意力分配至該區域，即便事故衝突或其他危險狀態極難避免，然而駕駛人仍須立即採取技術性行車作業進行避讓，例如緊急煞車，藉以降低事故嚴重程度。圖 5 為影響關鍵領域形狀與大小的重要因素。

關鍵領域之安全邊界受限於駕駛人在特定速度與環境條件下，面對事件發生時的減速能力。最小煞車距離主要受到駕駛人的反應能力、環境條件以及在各種路面條件下車輛本身減速能力之影響，其中又以生理層面因素最為重要。疲勞程度與藥物酒精之使用會影響駕駛人對外在環境刺激的反應能

力，在疲勞駕駛或是使用酒精藥物的狀況下，駕駛人會降低對外界的反應、減少警覺度、影響判斷，造成反應時間的增加，然而在此一生理條件下，駕駛人若能感受行車於高風險條件下而有所自覺，往往能夠提高警覺心，或是透過增加外在刺激提振精神以加強其反應能力 (Fuller，2005；Oron-Gilad *et al.*，2008)；年齡亦是影響反應能力之重要關鍵因素，根據交通部道安會 (2009) 統計，高齡駕駛者 (70 歲以上) 的反應時間較年輕駕駛增加 50%至 70%。除此之外，駕駛工作本身以及所處之駕駛環境亦會影響最小反應時間，若駕駛人必須執行之工作較為複雜，須要耗費較多時間認知危險狀況並做出決策，將導致其反應時間增加。

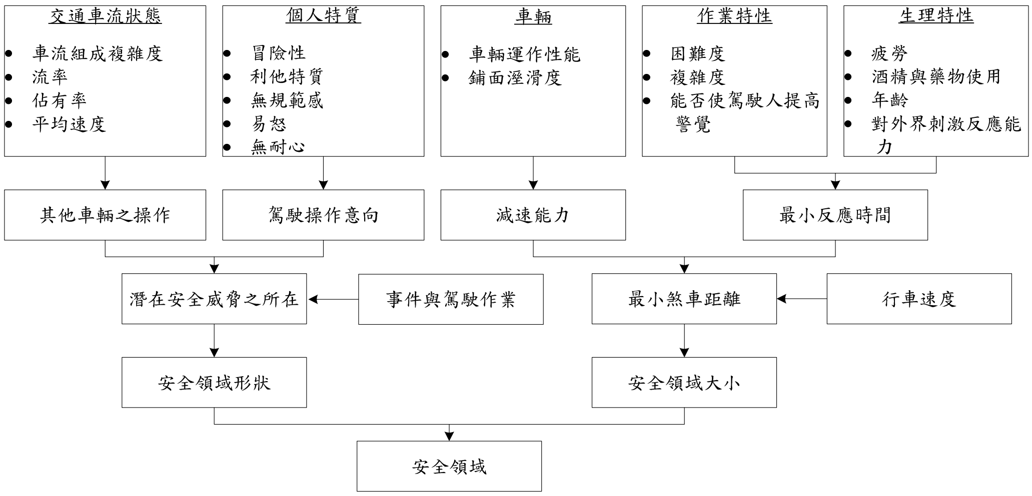


圖 5 關鍵領域之重要影響因素

關鍵領域的形狀取決於事件本身特性以及駕駛人依其意向所採取之行為，此一領域反映潛在風險的所在位置，以及可能發生軌跡衝突的方向，駕駛人必須將注意力分配至該區域以避免衝突發生。面對每一事件的發生，駕駛人可能採取不同的操作策略，每一個操作會導致車輛採取不同的軌跡行駛，因此可能造成與駕駛環境中其他物體行進軌跡的衝突，以圖 6 為例，若駕駛人維持直行時 (圖 6A)，可能造成之行車衝突僅包含車輛前方之區域，此時，駕駛人的關鍵領域僅涵蓋行車方向的前後方，以避免與前後車發生追撞衝突，此外，為避免鄰近車道車輛突然變換車道，因此必須將關鍵領域延伸至鄰近車道的部份區域；然而若駕駛人欲變換車道時 (圖 6B)，可能產生之行車軌跡衝突即包含原行駛車道以及欲匯入車道之前後方區域，因車輛仍在行駛當中，駕駛人在成功變換車道前仍必須與前車維持安全車間距，同時，為變換車道，駕駛人必須將注意力轉移至鄰近車道的前後方，以尋求足夠間距以匯入車流；當駕駛人進入路口(圖 6C)，其關鍵領域則必須擴展至垂直方向的來車與行人。

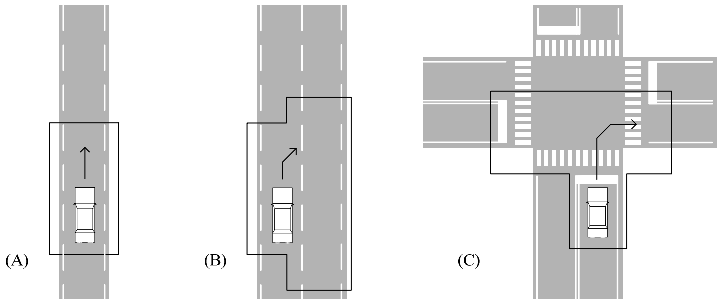


圖 6 不同駕駛操作之關鍵領域

(3) 觸發反應領域

當安全威脅出現在觸發反應領域內時，由於已接近關鍵領域，為避免該威脅接近或越過確保安全之臨界範圍，進而造成事故的發生，駕駛人會增加對其之注意力，並且隨時可能產生決策與相對應之駕駛操作。針對位處觸發反應領域內的安全威脅，駕駛人必須採取非技術性之行車作業，藉以持續監控該安全威脅的動態，並預測未來行進軌跡，判斷該威脅將會往認知領域方向遠離或持續接近關鍵領域，當駕駛人判斷該威脅可能危及行車安全時，則會採取技術性行車作業進行避讓。

圖 7 顯示影響觸發反應領域形狀與大小的各重要因素，觸發反應領域之邊界位置主要受到駕駛個人特性所影響，當駕駛人選擇將觸發反應邊界設在較遠處時，得以與安全威脅保持較大的車間距，並提供駕駛人更充裕的時間進行反應與行車操作，但是過大的觸發反應領域會導致駕駛人頻繁採取諸如加減速的行車操作，並增加無謂之工作量；反之，若駕駛人選擇將觸發反應邊界設在較近處時，則可減少駕駛人改變其行車動態的機會，但也同時縮短可供反應與操作的時間餘裕。駕駛經驗、技術與情境察覺能力為影響駕駛人選擇觸發反應邊界的主要因素，Elvik (2006) 提出的學習法則 (Law of learning) 認為事故率會隨著曝光量與駕駛經驗的累積而降低，具有豐富經驗的駕駛較能夠有效接收處理訊息，並且在恰當的時機點針對正確的威脅觸發下一階段心智活動，以投注更多的注意力並採取行車操作，當面對安全威脅時方能做出正確之判斷與決策 (Nabatilan，2007；Underwood *et al.*，2002)。除了經驗與訓練之外，過去研究發現駕駛人的個人特質、態度、自信心與風險認知等心理特徵亦會影響駕駛人的駕駛行為 (Chang and Yeh，2007；Taubman-Ben-Ari *et al.*，2004；Ulleberg and Rundmo，2003；Wong *et al.*，2010)，具有不同行為傾向的駕駛人所採取的決策會導致其觸發反應領域大小的差異。

觸發反應領域通常介於認知領域與關鍵領域之間，然而在特定條件下，三領域的邊界有時會出現極為接近甚至重疊的現象，例如在天候狀態極差的狀態下，視距受限，導致認知領域的邊界接近關鍵領域，於此狀態下，安全

威脅必須要到非常接近安全臨界點時才會被發現，此時駕駛人必須在發現安全威脅同時馬上進行反應，或是降低車速以縮小關鍵領域，增加可供反應之空間。

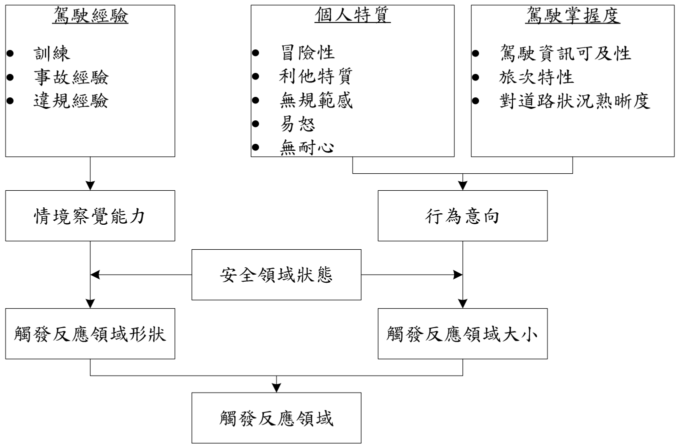


圖 7 觸發反應領域之重要影響因素

駕駛人對於駕駛的掌控程度亦會影響觸發反應領域的設定，若駕駛人得以取得駕駛環境的相關資訊，例如路況、天候或路徑規畫導航等，能夠增加對於駕駛的掌控程度，當駕駛人感覺越有信心時，越能夠妥善設定觸發反應領域，並事先針對可能面臨到的交通狀況進行準備與調整，藉以降低負荷；反之，當預期的狀況與實際交通狀況有所差距時，駕駛人容易感覺到疲倦與壓力 (Hill and Boyle，2007)，進而使駕駛人無法妥善設置觸發反應領域，導致無法有效分配其注意力。

觸發反應領域的形狀同樣受到駕駛人行為特性、決策能力，以及注意力分配的策略之影響；關鍵領域的形狀反映在特定駕駛行為操作與特定環境下，可能造成行車衝突的位置與方向，然而為避免威脅接近關鍵領域進而造成事故風險，觸發反應領域的形狀應與關鍵領域類似，方能有效避免危險狀況發生。然而如同上述對於觸發反應領域大小的討論，經驗、技術等因素決定駕駛人是否有足夠知識將注意力分配在正確的車輛或物體上，若將觸發反應領域設定錯誤，導致在特定方向上觸發反應領域的邊界與關鍵領域邊界過於接近，將導致駕駛人無法有效分配注意力以及早發現安全威脅，並且縮短安全威脅被發現後，駕駛人得以採取行車操作的空間。

2. 安全威脅與駕駛人認知風險水準

安全威脅代表在駕駛環境當中可能損及行車安全之潛在危險，駕駛人須將其視為重要的潛在注意力焦點，為了解各個安全威脅在行車過程中與駕駛人的互動，以及帶給駕駛人的注意力需求，本研究透過距離、操作互動與相對位置三維

度將安全威脅進行分類，並探討駕駛人針對各個採取不同操作、位處不同位置距離的安全威脅所認知的風險水準。考量駕駛人係依據個人對於外界環境的解讀、認識與理解分配其注意力，結合了安全威脅與駕駛人互動狀態，認知風險水準可被視為各個安全威脅的認知需求，並為影響注意力分配策略的重要變數。本節將說明上述三維度於安全威脅與駕駛人互動過程中所代表之意含，同時說明在不同車流狀態下，各個安全威脅的風險水準。

衡量認知風險水準的第一個維度為距離，本研究將安全威脅與駕駛人之間的距離透過車輛領域加以詮釋；人們在接受視覺刺激時會傾向同時接收含括一區域的圖像而非單一個體，以觀察道路上的車輛為例，駕駛人將注意力移轉至某一輛車時，其視線不僅針對該車輛，同時也會接收到該目標車輛周圍一定範圍內的其他動態，尤其在觀察無車輛佔據的道路區域時，駕駛人看到的一塊特定面積的區域，而非一個焦點；同時駕駛人在觀察路況時，視線往往得以向目標物的前後方延伸，透過車輛領域之設定可以反映駕駛人接受視覺刺激之特性；此外，車輛領域同時反映駕駛人面對不同距離外的安全威脅所採取之策略差異，其中唯有進入駕駛人所認定之觸發反應領域才會激發較高程度的注意力，藉由三個車輛子領域的設定，本研究得以呈現不同威脅所激發的注意力投入量。衡量認知風險水準的第二個維度為駕駛操作，本研究僅探討車輛在路段行駛時的注意力分配，不考慮機慢車、行人或是路口之干擾，因此得以將駕駛人的操作簡化為下列四種：維持速度、減速、加速與變化車道，駕駛人本身與安全威脅皆可採取此四類操作，當兩者的互動會導致車間距縮小時，意味此一情境會造成駕駛人感受到較高的事故風險，因而必須分配較多的注意力至該活動上。衡量認知風險水準的第三個維度為安全威脅與駕駛人的相對位置，為簡化模式，本研究設定駕駛人行駛於最內側車道，因此模式無須同時考慮來自左右方的威脅，因此可將複雜之雙車 (S 車為駕駛人本身、T 車為安全威脅) 互動簡化為圖 8 的六個情境。

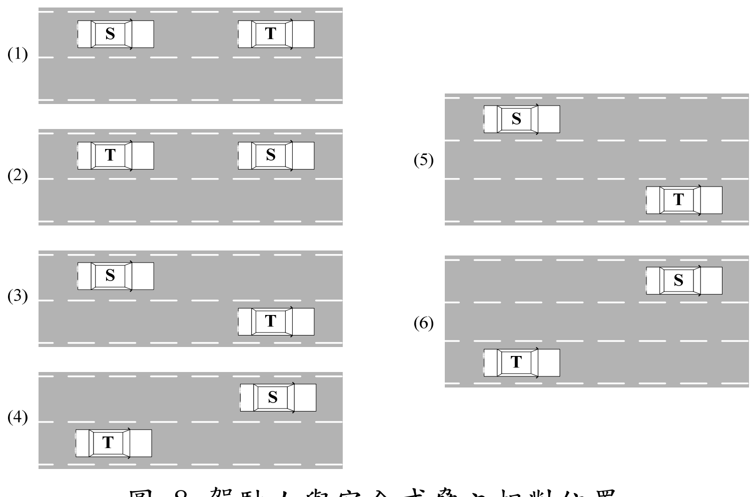


圖 8 駕駛人與安全威脅之相對位置

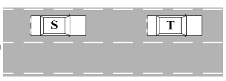
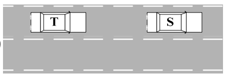
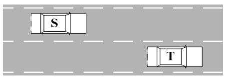
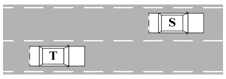
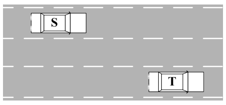
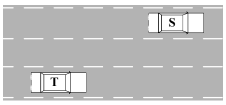
第一與第二個情境為兩車行駛於同一車道，其中情境一為安全威脅位於駕駛人前方車道，情境二為安全威脅位於駕駛人後方，當兩車位於同一車道時，駕駛

人必須將注意力集中在可能造成追撞事故的安全威脅。第三與第四個情境為兩車分別行駛於鄰近的兩車道，其中情境三表示安全威脅位於駕駛人的右前方，情境四表示安全威脅位於駕駛人的右後方，當駕駛人持續往前行而未採取變換車道時，除了必須注意情境一、二當中所說明的前後車外，尚須將注意力分配至鄰近車道，避免當鄰近車輛變換至目前所行使車道時，造成可能的風險；反之，當駕駛人欲變換車道時，同樣仍然必須關注同車道前方的車輛並在成功變換車道前維持安全車間距，此外，駕駛人亦須觀察鄰近車道的前後車，藉以在適當時機變換車道。第五與第六個情境為兩車中間仍相隔一車道的狀況，駕駛人在變換車道時必須小心位處該情境當中的安全威脅是否也會同時變換車道，造成兩車於中間的車道發生衝突。

結合距離、相對位置與行車操作，本研究得以將道路駕駛環境內的安全威脅加以區分並調查駕駛人對於各類威脅之認知風險水準，此外，外界車流環境亦會影響駕駛人對於各安全威脅之認知，表 1 至表 3 為本研究整理在自由流 (Free flow)、同步流 (Synchronized flow) 與擁擠流 (Congested flow) 狀態下，駕駛人對於不同類型安全威脅的認知風險水準，此一風險水準並未經實驗調查，僅為研究者對於各狀況之主觀認知所提出的一般狀況，後續研究仍須針對此一指標進行調查。

表 1 為駕駛人於自由流狀態下，面對位於不同車輛領域、位置並採取不同操作的安全威脅，所認知其對自身行車安全的風險水準，鑒於自由流係指駕駛人不會受到其他車流影響而得以自由行駛，根據本研究對三個車輛子領域之定義，駕駛人針對位於觸發反應領域內的安全威脅會投入較高的注意力並隨時可能採取技術性行車作業，若安全威脅靠近或進入關鍵領域則須立即採取避讓措施，因此於本階段，唯有當觸發反應領域與關鍵領域無車輛時方能符合自由流之特性。當行駛於自由流狀態下，駕駛人僅會接受到前方車輛所帶來的威脅 (如情境一、三、五)，唯有當駕駛人欲變換車道時，來自鄰近車道的後方車輛才會造成衝突風險的增加 (如情境四、六)。此外，由於認知領域距離尚遠，駕駛人針對遠處安全威脅所認知的風險水準較低，唯有當兩車的操作可能使車間距縮小 (例如駕駛人加速時前方車輛減速)，使得該安全威脅可能進入觸發反應領域時，其認知風險才會增加。

表 1 自由流狀態下的認知風險水準

駕駛人採取之行車操作 ＼ 安全威脅所採取之行車操作		駕駛人行駛於自由流											
		認知領域				觸發反應領域				關鍵領域			
安全威脅之相對位置	駕駛操作	維持速度	加速	減速	變換車道	維持速度	加速	減速	變換車道	維持速度	加速	減速	變換車道
(1) 	維持速度	L	L	-	-								
	加速	-	L	-	-								
	減速	M	M	-	L								
	變換車道	-	-	-	L								
(2) 	維持速度	-	-	-	-								
	加速	-	-	L	-								
	減速	-	-	-	-								
	變換車道	-	-	-	-								
(3) 	維持速度	-	L	-	L								
	加速	-	-	-	-								
	減速	L	L	-	M								
	變換車道	L	L	-	-	不適用於自由流狀態				不適用於自由流狀態			
(4) 	維持速度	-	-	-	-								
	加速	-	-	-	L								
	減速	-	-	-	-								
	變換車道	-	-	-	-								
(5) 	維持速度	-	-	-	-								
	加速	-	-	-	-								
	減速	-	-	-	-								
	變換車道	-	-	-	L								
(6) 	維持速度	-	-	-	-								
	加速	-	-	-	-								
	減速	-	-	-	-								
	變換車道	-	-	-	L								

S 車：駕駛人本身

T 車：安全威脅

認知風險水準

- ：無風險
L ：低度風險
M ：中度風險
H ：高度風險
D ：危險狀態

表 2 為駕駛於同步流狀態下，駕駛人對各安全威脅的認知風險水準。同步流係指駕駛人行車受到鄰近車輛影響而無法自由選擇速度行駛，亦及在駕駛過程當中，觸發反應領域內會持續存在車輛，甚至隨時會有車輛接近關鍵領域。於此階段，駕駛人對於觸發反應領域以及關鍵領域內的安全威脅會認知到較高的風險水準。面對同步車流，位於三個車輛子領域內的車輛皆會對駕駛人產生威脅感，然而由於車輛多集中於觸發反應領域內，多數在該領域內的車輛都會被駕駛人視為可能造成事故風險的安全威脅，其中持續縮小車間距的安全威脅所帶來的認知

風險較高，其餘車輛則仍保持較輕微的認知風險水準。對駕駛人而言，認知領域內唯有可能脫離認知領域而進入觸發反應領域的車輛會使駕駛人感到風險，其他車輛不會對駕駛人造成影響。此外，於同步車流中，駕駛人可能偶爾會面臨到安全威脅接近甚至行駛在關鍵領域之邊界上，此時駕駛人會認知到較高的風險水準，部份接近關鍵領域的威脅若仍持續往駕駛人方向移動，則其認知風險水準將達到危險等級，駕駛人必須立即反應以避免衝突。

表 2 同步流狀態下的認知風險水準

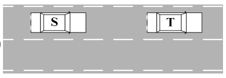
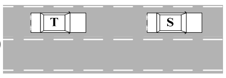
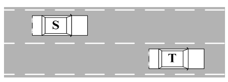
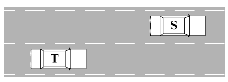
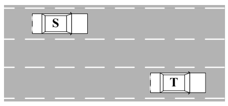
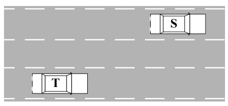
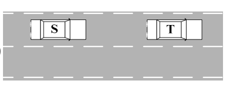
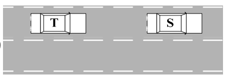
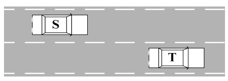
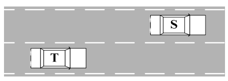
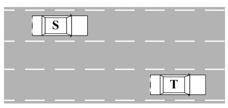
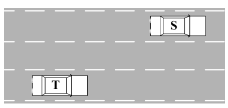
駕駛人採取之行車操作 / 安全威脅所採取之行車操作		駕駛人行駛於同步流											
		認知領域				觸發反應領域				關鍵領域			
安全威脅之相對位置	駕駛操作	維持速度	加速	減速	變換車道	維持速度	加速	減速	變換車道	維持速度	加速	減速	變換車道
(1) 	維持速度	-	L	-	-	M	M	-	L	H	H	M	M
	加速	-	-	-	-	L	M	-	-	M	H	L	-
	減速	L	L	-	-	M	H	M	L	H	D	M	H
	變換車道	-	-	-	L	-	L	-	M	M	M	L	H
(2) 	維持速度	-	-	-	-	L	-	L	-	M	M	M	L
	加速	-	-	L	-	M	L	M	L	H	M	H	M
	減速	-	-	-	-	-	-	-	-	M	L	L	-
	變換車道	-	-	-	-	-	-	-	-	L	-	L	M
(3) 	維持速度	-	L	-	L	L	M	-	M	M	M	L	H
	加速	-	-	-	-	-	L	-	L	L	M	-	M
	減速	-	L	-	L	L	H	L	H	H	H	M	D
	變換車道	L	L	-	-	M	H	L	L	H	D	M	M
(4) 	維持速度	-	-	-	-	-	-	-	M	M	L	L	M
	加速	-	-	-	-	L	L	L	H	M	M	M	H
	減速	-	-	-	-	-	-	-	L	L	-	M	M
	變換車道	-	-	-	-	L	L	M	M	M	L	M	L
(5) 	維持速度	-	-	-	-	-	-	-	L	-	-	-	-
	加速	-	-	-	-	-	-	-	-	-	-	-	-
	減速	-	-	-	-	-	-	-	L	-	-	-	L
	變換車道	-	-	-	L	L	M	-	M	-	-	-	L
(6) 	維持速度	-	-	-	-	-	-	-	-	-	-	-	-
	加速	-	-	-	-	-	-	-	L	-	-	-	-
	減速	-	-	-	-	-	-	-	-	-	-	-	-
	變換車道	-	-	-	-	-	-	L	M	-	-	-	L

表 3 為駕駛於擁擠流狀態下，駕駛人對各安全威脅的認知風險水準。行駛在擁擠流狀態時，前後車之車間距極小 (Bump to bump)，駕駛人必須頻繁切換油門與剎車，藉以確保在前進的同時尚能避免與前車發生衝突。行駛於此狀態下，駕駛人會對前方的車流保持極高的認知風險，造成無暇顧及後方車流 (例如情境二)，此外，由於最接近駕駛人的車輛多已位處關鍵領域邊緣，其他領域的

車輛不會對駕駛人產生任何影響。針對行駛於鄰近車道的車輛，考量駕駛人與前方車輛的車間距明顯無法容納其他車輛匯入，因此除非駕駛人本身欲變換車道，或是有其他車輛試圖匯入，否則位於鄰近車道之車輛對駕駛人的影響有限。

表 3 擁擠流狀態下的認知風險水準

駕駛人採取之行車操作 ＼ 安全威脅所採取之行車操作		駕駛人行駛於擁擠流											
		認知領域				觸發反應領域				關鍵領域			
安全威脅之相對位置	駕駛操作	維持速度	加速	減速	變換車道	維持速度	加速	減速	變換車道	維持速度	加速	減速	變換車道
(1) 	維持速度	-	-	-	-	-	-	-	-	H	D	M	H
	加速	-	-	-	-	-	-	-	-	M	H	L	L
	減速	-	-	-	-	-	-	-	-	D	D	H	D
	變換車道	-	-	-	-	-	-	-	-	H	D	L	H
(2) 	維持速度	-	-	-	-	-	-	-	-	-	-	-	-
	加速	-	-	-	-	-	-	-	-	-	-	-	-
	減速	-	-	-	-	-	-	-	-	-	-	-	-
	變換車道	-	-	-	-	-	-	-	-	-	-	-	-
(3) 	維持速度	-	-	-	-	-	-	-	M	-	-	-	H
	加速	-	-	-	-	-	-	-	L	-	-	-	M
	減速	-	-	-	-	-	-	-	H	-	-	-	D
	變換車道	-	-	-	-	-	-	-	L	H	H	H	M
(4) 	維持速度	-	-	-	-	-	-	-	M	-	-	-	H
	加速	-	-	-	-	-	-	-	H	-	-	-	D
	減速	-	-	-	-	-	-	-	L	-	-	-	M
	變換車道	-	-	-	-	-	-	-	-	-	-	-	-
(5) 	維持速度	-	-	-	-	-	-	-	-	-	-	-	-
	加速	-	-	-	-	-	-	-	-	-	-	-	-
	減速	-	-	-	-	-	-	-	-	-	-	-	-
	變換車道	-	-	-	-	-	-	-	-	-	-	-	-
(6) 	維持速度	-	-	-	-	-	-	-	-	-	-	-	-
	加速	-	-	-	-	-	-	-	-	-	-	-	-
	減速	-	-	-	-	-	-	-	-	-	-	-	-
	變換車道	-	-	-	-	-	-	-	-	-	-	-	-

認知風險水準為影響注意力需求的重要指標，結合距離、位置、操作等維度，該指標呈現駕駛環境當中每一個體與駕駛人之互動狀態，並可被視為駕駛人面對其他車輛駕駛活動對行車安全所產生的危機感。認知風險水準為依主觀性量度指標，其仰賴駕駛人對於環境的認識與想法，因此，異質性可能造成不同屬性的駕駛人面對同一安全威脅而產生相異的認知風險，進而導致在注意力分配策略上的差異。縱使本研究未針對駕駛人異質性多所著墨，然而後續研究仍應針對此一課題深究，唯有解構駕駛人認知風險對注意力分配之關係，方能更進一步了解駕駛人是如何在行車過程中移轉其注意力焦點。

肆、駕駛注意力分配模式

個體選擇模式 (Discrete choice model) 在運輸領域常被應用於分析使用者運具選擇行為，依據個體經濟學效用最大化之概念，將潛在影響變因納入效用函數，以建構個體選擇行為之預測模式。本研究應用個體選擇模式，以駕駛人認知風險為基礎，另將安全威脅各種狀態與行車資訊收集等變數納入模式，藉以建構注意力需求函數，透過模式之建立與校估，研究者可求得特定注意力選擇的方案，在不同的交通狀況、威脅特性以及駕駛人資訊需求下被選擇作為下階段注意力焦點之機率。注意力分配的過程當中，注意力分配策略之形成最為關鍵，圖 2 僅初步界定該策略於注意力分配流程中之定位，並將眾多輸入資料歸納為三大類決策變數：認知風險評估、定向反應、行車資訊收集；以圖 2 為基礎，本章將近一步剖析說明於注意力分配的過程當中，駕駛人應接收的資訊，以及輸入資料轉化至模式決策變數之邏輯，作為建構駕駛注意力分配模式之基石。

於本研究中，潛在注意力焦點選擇方案可分為兩大類：道路區域與行車資訊源，其中道路區域包含三車輛子領域與六個安全威脅相對位置所構成之 18 個方案，行車資訊則包含在資訊所在之車輛子領域，以及路旁與路側資訊兩類相對位置共六個方案。駕駛為一持續不間斷的的選擇過程，於行車當中，駕駛人必須隨時自短期記憶內提取相關資訊作為注意力焦點方案選擇之輸入值，藉由注意力分配策略 (注意力焦點方案選擇機率) 的形成，選擇其中一處做為注意力焦點，收集相關資訊後回饋並更新至短期記憶，接著再進行下階段的選擇。其中，駕駛人必須自短期記憶內提取並更新的資訊包含安全威脅動態、行車資訊，此外尚包含駕駛人特質。

各個安全威脅動態包含該威脅目前位於道路上的哪一區域，以及該威脅的相關動態，包含正在執行的行車操作、是否剛變換狀態、是否新奇 (Novel) 與是否複雜。相關變數說明如下：

- $T_{i,j,k}$：車輛領域內，各個道路區域的是否有安全威脅 (車輛) 存在，以及該對應車輛之行車操作。當 $T_{i,j,k} = 1$ 時，代表在第 i 個車輛子領域與第 j 個位置有其他車輛存在，而該車輛正在執行第 k 種操作。其中 i = 1~3，分別代表認知領域、觸發反應領域與關鍵領域；j = 1~6，分別代表圖 8 中的六個情境；i = 1~4，分別代表維持速度、加速、減速與變換車道四種操作。
- $T'_{i,j,k}$：上一時階車輛領域各個道路區域及安全威脅的動態。
- $Sc_{i,j}$：位於第 i 個車輛子領域與第 j 個位置的安全威脅是否剛變換狀態，當 $Sc_{i,j} = 1$ 時，代表該威脅剛變換狀態。
- $N_{i,j}$：位於第 i 個車輛子領域與第 j 個位置的安全威脅是否新奇，當 $N_{i,j} =$ 1 時，代表該威脅被駕駛人視為新奇的事物。

- $Co_{i,j}$：位於第 i 個車輛子領域與第 j 個位置的安全威脅之操作是否複雜，當 $Co_{i,j} = 1$ 時，代表該威脅操作狀態複雜。
- $F_{i,j}$：於本階段，駕駛人所選擇的道路區域注意力焦點，當 $F_{i,j} = 1$ 時，代表第 i 個車輛子領域與第 j 個位置的區域於本階段被駕駛人選為注意力焦點。
- $F'_{i,j}$：於上一階段，駕駛人所選擇的道路區域注意力焦點，當 $F'_{i,j} = 1$ 時，代表第 i 個車輛子領域與第 j 個位置的區域於上階段被駕駛人選為注意力焦點。
- $f_{i,m}$：於本階段，駕駛人所選擇的行車資訊注意力焦點，當 $f_{i,m} = 1$ 時，代表第 i 個車輛子領域與第 m 個位置的行車資訊於本階段被駕駛人選為注意力焦點。
- $f'_{i,m}$：於上一階段，駕駛人所選擇的行車資訊注意力焦點，當 $f'_{i,m} = 1$ 時，代表第 i 個車輛子領域與第 m 個位置的行車資訊於上階段被駕駛人選為注意力焦點。
- $Speed$：駕駛人之行車速度

行車資訊狀態包含該資訊源目前位於道路上的哪一區域，以及該資訊的相關屬性，包含資訊內涵種類、是否已於前階段辨識過。相關變數說明如下：

- $I_{i,m}$：車輛領域內，各個道路區域是否有行車資訊的資訊源存在。當 $I_{i,m} = 1$ 時，代表在第 i 個車輛子領域與第 m 個位置有資訊源存在。其中 $m = 1$、2，分別代表路中 (On-road) 與路側 (Off-road)。
- $Id_{i,m}$：位於第 i 個車輛子領域與第 m 個位置的資訊源是否已被觀察過，當 $Id_{i,m}= 1$ 時，代表該資訊源已被駕駛人所辨識並觀察。
- $Te_{i,m}$：資訊內涵種類，當 $Te_{i,m} = 1$ 時，代表該資訊源為文字介面，反之，當，$Te_{i,m} = 0$ 時則為圖像介面。

除了必須隨時持續更新提取的短期記憶外，駕駛人相關屬性亦會影響注意力需求的變化，本研究納入之駕駛人相關屬性變數如下：

- $R_{i,j,k}$：駕駛人對車輛領域內各個安全威脅採取不同駕駛操作時的認知風險水準 (如表 1 至表 3)，認知風險水準受到駕駛人本身訓練、經驗、個性以及其他心理特質所影響，於行車過程當中，不會受到即時交通狀況與資訊接受的改變。
- Fa：駕駛人對道路狀況、路徑等資訊的了解程度，當 $Fa = 1$ 時，代表駕駛人對道路狀況、路徑等具有相當程度的熟識。

圖 9 為注意力分配模式之架構，基於駕駛人自道路駕駛環境所收集的資料與駕駛人本身對駕駛環境的認知，注意力需求函數 (即效用函數) 之決策變數可分為三大類，分別為認知風險水準、定向反應與行車資訊取得。

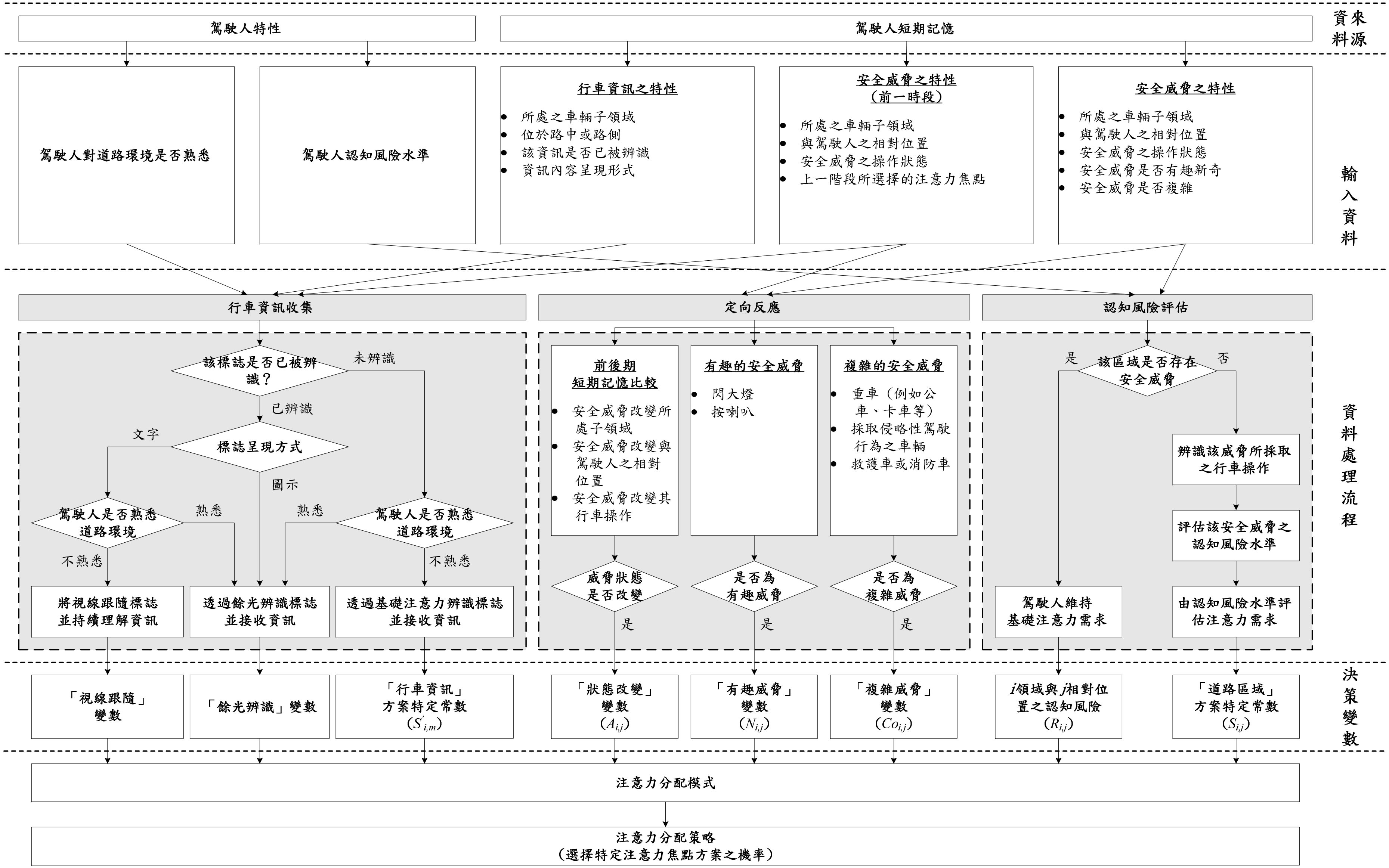


圖 9 注意力分配模式架構圖

1. 認知風險

於本研究所提出之注意力分配模式中，認知風險水準為影響注意力需求之重要變數，此類型變數之輸入資料包含駕駛人自短期記憶中提取的安全威脅狀況，以及受到個別駕駛人特性影響之認知風險水準。以三個車輛子領域與六個相對位置為基準，駕駛人注意力所及的道路駕駛環境範圍可切割為 18 個區域，以作為注意力分配之潛在目標。根據自短期記憶提取的資料，當某一特定區域被安全威脅所佔據時，駕駛人必須進一步判斷該安全威脅目前採取的行車操作，並參照認知風險水準表 (如表 1 至表 3) 取得該安全威脅在特定行車操作下的認知風險水準 ($r_{i,j}$) 並納入模式[i]。

駕駛人對每一區域皆會保持不同程度的基礎注意力需求，藉以反映駕駛人進行注意力分配的獨特形態，例如在持續直行不變換車道狀況下，駕駛人會分配較多的注意力在前方，此外基礎注意力亦反映當某一區域無任何安全威脅或其他物體存在時，駕駛人仍會維持一定程度的情境察覺之能力，避免該區域突然出現安全威脅；藉由個體選擇模式之參數校估，各個道路區域的基礎注意力得以透過道路安全威脅之方案特定常數 ($S_{i,j}$) 加以呈現。此外，考量駕駛人注意力焦點的選擇會受到上階段設定注意力的位置所影響，使注意力移轉形成一特定的次序型態，本研究將上一階段所選之注意力焦點納入為決策變數，藉以呈現駕駛人移轉其注意力之特性。

2. 定向反應

注意力分配模式的第二類決策變數為定向反應，係指在視覺可及的環境中，造成駕駛人潛意識視覺移轉的外在刺激，包含狀態改變、新奇威脅、複雜威脅三種。當人們發現一突然改變其狀態的物體時，會下意識的將視線轉移至該物體上，即便該物體並無提供任何有效資訊，亦非注意力分配過程當中值得觀察的目標；駕駛過程中，透過前後期短期記憶之比較，若發現有安全威脅的狀態改變 (State changes) 時 ($T_{i,j,k} - T'_{i,j,k} \neq 0$)，包括某一安全威脅改變所處之子領域、相對位置或行車操作，駕駛人會傾向分配較多的注意力於該威脅上。本研究加入一「狀態改變」虛擬變數 ($Sc_{i,j}$)，藉以呈現當駕駛人發現位於 i 領域 j 相對位置的安全威脅狀態改變時，額外增加之注意力需求。

第二類定向反應為「新奇的 (Novel)」威脅，新奇性 (novelty) 為一物體產生與人們預期不一致的行為或現象，為與「狀態改變」所產生之定向反應做區隔，本研究將新奇威脅定義為吸引駕駛人瞬時性注意力移轉之突發刺激，例如其他車輛閃大燈或按喇叭等；其中瞬時性為新奇威脅之重要特性，駕駛人僅有在該安全

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[i] $r_{i,j}$ 為駕駛人針對位於 i 領域 j 相對位置的安全威脅，在特定行車操作下的認知風險，可由 $r_{i,j} = R_{i,j,k} \cdot T_{i,j,k}$ 求得。

威脅出現新奇現象的瞬間才會增加注意力需求，當下一瞬間該新奇性消失後，注意力需求則回歸常態。本研究加入一「新奇威脅」虛擬變數 ($N_{i,j}$)，藉以呈現當位於 i 領域 j 相對位置的安全威脅產生新奇的行為或現象時，額外增加之注意力需求。

第三類定向反應為「複雜的 (Complex)」威脅，相對於新奇威脅的瞬時反應，複雜威脅可被定義造成駕駛人感到壓力，並且吸引駕駛人持續性注意力移轉與追蹤的安全威脅，例如面對救護車、消防車時必須持續追蹤以讓道，亦或是駕駛人會傾向遠離重車或侵略性高之車輛；複雜威脅的存在會維持一段較長之時間，唯有當該複雜威脅脫離視線所及範圍後，駕駛人方能解除對其之高度關注。本研究加入一「複雜威脅」虛擬變數 ($Co_{i,j}$)，藉以呈現當位於 i 領域 j 相對位置的安全威脅因其車輛特性或操作型態造成駕駛人壓力，進而影響行車操作時，必須額外增加之注意力需求。

3. 行車資訊收集

注意力分配模式的第三類決策變數為行車資訊收集，本研究現階段僅著重於道路環境中，可提供駕駛人行車資訊的標誌作為資訊源，目前並未考慮其他諸如車內資訊系統等資訊源對注意力分配之影響。駕駛人辨識並理解行車資訊標誌的途徑分為三種：透過基礎注意力主動搜尋、藉由餘光被動接收與視線跟隨 (Visual pursuit)，駕駛人辨識標誌途徑的差異主要受到下列三個因素影響：該標誌是否已被辨識過、標誌內容呈現方式與駕駛人對道路環境是否熟悉；此外，考量行車標誌多為單面，駕駛人僅能從正面了解其意義，再者，透過後視鏡難以清楚理解行車資訊，因此本研究對行車資訊收集之討論僅涵蓋車輛前方之道路區域 (相對位置情境一、三、五)。

首先，行車資訊標誌可被分為尚未被辨識 ($Id_{i,m} = 0$) 與已於前階段被駕駛人所辨識 ($Id_{i,m} = 1$) 兩類。面對尚未被辨識之行車資訊標誌，在駕駛人的短期記憶中並無該標誌之存在，因此必須透過餘光被動搜尋或是透過基礎注意力的主動搜尋，兩者差異取決於駕駛人對於道路狀況是否有足夠的熟悉度。當該駕駛人對於道路駕駛環境 (路徑、行車規範、速限等) 有足夠了解時 ($Fa = 1$)，行駛過程較不需要外在資訊的協助，因此，標誌的接收僅會透過駕駛者的餘光接收；行車資訊標誌的所在位置可分為路中 (On-road) 與路側 (Off-road)，當未被辨識的新資訊位於認知領域時，由於距離較遠，駕駛人中央視角可涵蓋的範圍較廣，只要當駕駛人將視線移轉至認知領域 ($F'_{1,1} = F'_{1,3} = F'_{1,5} = 1$) 時，無論是路側 ($I_{1,1}$) 或是路中 ($I_{1,2}$) 的標誌皆能被其餘光所接收，然而當未被辨識的新資訊位於觸發反應領域時，路側標制僅有在駕駛人將視線移轉至觸發反應領域的前方車道與鄰近車道區域 (相對位置情境一、三) 時才會被餘光範圍涵蓋，若路中標誌則是在駕駛人將視線移轉至觸發反應領域的鄰近車道與鄰近的第二條車道時 (相對位置

情境三、五) 才會被餘光接收。本研究加入「餘光辨識」虛擬變數 ($Pe_{i,m}$)，藉以呈現當駕駛人對道路駕駛環境熟悉時，是否得以透過餘光辨識位於 i 領域 m 位置的行車標誌資訊，「餘光辨識」虛擬變數包含 $Pe_{1,1}$ [ii]、$Pe_{1,2}$ [iii]、$Pe_{2,1}$ [iv]與 $Pe_{2,2}$ [v]，分別代表位於認知領域路中、認知領域路側、觸發反應領域路中、觸發反應領域路側的行車標誌資訊。

反之，若駕駛人對於道路駕駛環境並不熟悉 ($Fa = 0$)，行駛過程中較需要外在資訊的協助，藉以確認行車方向、路徑與相關行車規範，因此駕駛人會對位於認知領域與觸發反應領域的路側、路中區域維持基礎注意力需求，隨時主動搜尋道路環境中的各個區域，以找尋行車標誌並收集相關資訊。藉由個體選擇模式之參數校估，各個行車標誌資訊的基礎注意力得以透過行車資訊收集之方案特定常數 ($S'_{i,j}$) 加以呈現。

一但特定標誌已被辨識後，駕駛人對於道路環境是否熟悉與標誌內容呈現方式決定駕駛人視線是否會持續跟隨該號誌，以進一步理解該標誌之內涵意義。標誌呈現方式可分為圖像 ($Te = 0$) 與文字 ($Te = 1$)，圖像標誌為透過符號或簡單字彙表達的標誌，例如「停」或禁止進入，圖像標誌能提供的資訊量較少，但是可供駕駛人在接收資訊的瞬間迅速理解，因此於下一時段不會額外增加注意力資源在圖像標誌上以求更理解標誌內容。反之，文字標誌目的通常為提供駕駛人相關較大量的訊息，例如目的地距離、替代道路或路況等，然而由於資訊量龐大，駕駛人必須耗費較多的時間與心力閱讀並理解文字，因此當駕駛人對路況不熟悉時，接收到文字訊息後會傾向持續追蹤，以取得相關資訊，然而若駕駛人對道路駕駛環境熟悉時，文字訊息代表之意含與圖像訊息相似，駕駛人在辨識該訊息後即不再持續跟隨。本研究加入「視線跟隨」虛擬變數 ($Vp_{i,m}$)[vi]，藉以呈現對道路環境不熟悉的駕駛人，在接收位於道路不同區域的文字訊息後，所產生的跟隨現象。

綜合以上對注意力分配模式之說明，本研究將決策變數彙整如表 4，其中共生變數包含前階段所選之注意力焦點，並納入行車速度 (*Speed*) 探討在不同速度下，駕駛人注意力是否會呈現較為集中的趨勢；此外，本研究採用之方案特定變數則包含駕駛人認知風險水準、狀態改變、新奇威脅、複雜威脅、餘光辨識與視線跟隨等變數。

[ii] $Pe_{1,1} = Fa \cdot I_{1,1} \cdot (F'_{1,1} + F'_{1,3} + F'_{1,5})$

[iii] $Pe_{1,2} = Fa \cdot I_{1,2} \cdot (F'_{1,1} + F'_{1,3} + F'_{1,5})$

[iv] $Pe_{2,1} = Fa \cdot I_{2,1} \cdot (F'_{1,1} + F'_{1,3})$

[v] $Pe_{2,2} = Fa \cdot I_{2,2} \cdot (F'_{1,3} + F'_{1,5})$

[vi] $Vp_{i,m} = (1 - Fa) \cdot I_{i,m} \cdot Te_{i,m} \cdot Id_{i,m}$

表 4 注意力分配模式變數定義

選擇方案與注意力需求函數	
1. $V_{i,j}$	：道路區域的注意力需求函數
2. $V'_{i,m}$	：行車資訊收集的注意力需求函數
i	：符號下標，表車輛領域 (1：認知領域、2：觸發反應領域、3：關鍵領域)
j	：符號下標，表安全威脅對駕駛人之相關位置 (如圖 8)
m	：符號下標，表行車標誌位置 (1：路中、2：路側)
方案特定常數	
3. $S_{i,j}$	：道路區域的注意力需求函數之方案特定常數，於本研究可視為各個道路區域的基礎注意力
4. $S'_{i,m}$	：行車資訊收集的注意力需求函數之方案特定常數，於本研究可視為各個行車資訊源的基礎注意力.
共生變數	
5. $F'_{i,j}$	：駕駛人前一階段所選之注意力焦點，若道路區域 ij 於上階段被選，其值為 1，否則為 0
6. *Speed*	：駕駛人之車速
方案特定變數	
7. $r_{i,j}$	：駕駛人對安全威脅 ij 的認知風險水準
8. $A_{i,j}$	：狀態改變虛擬變數，若安全威脅 ij 之狀態與前階段不一致，其值為 1，否則為 0
9. $N_{i,j}$	：新奇威脅虛擬變數，若安全威脅 ij 為一新奇威脅，其值為 1，否則為 0
10. $Co_{i,j}$	：複雜威脅虛擬變數，若安全威脅 ij 為一複雜威脅，其值為 1，否則為 0
11. $Pe_{i,m}$	：餘光辨識虛擬變數，若行車資訊源 ij 可被駕駛人餘光範圍涵蓋，其值為 1，否則為 0
12. $Vp_{i,m}$	：視線跟隨虛擬變數，若行車資訊源 ij 可會導致駕駛人以視線持續跟隨追蹤，其值為 1，否則為 0

本研究提出注意力分配模式之目的在於提供探討駕駛人注意力分配之工具，透過個體選擇模式之應用，注意力分配模式得以納入認知風險、定向反應與行車資訊取得等三大類影響注意力焦點選擇機率的變數，藉由實驗設計、資料收集與參數校估，了解各個影響因素對注意力需求之貢獻程度。本模式之主要特點為提供一即時性的個體注意力選擇行為分析工具，此外，不同於過去僅考量注意力需求最高的物體，透過選擇機率的呈現與短期記憶的機制，駕駛人得以將注意力需求較低的安全威脅或道路區域設為注意力焦點，並納入短期記憶當中作為後續注意力分配與行車操作執行的依據。駕駛過程為不斷輪迴的選擇過程，駕駛人持續自短期記憶內提取資料，根據記憶中所認知的車輛領域狀態進行注意力焦點選擇，並收集與更新資訊以進行下階段的注意力分配。

現階段本研究僅提出注意力分配模式之架構，並且定義其中重要的影響因素與操作方式，後續研究仍須進行實證資料之收集與模式參數校估。其中駕駛人對各安全威脅的認知風險水準為影響注意力需求之重要輸入資料，於本研究當中，該認知風險水準僅呈現研究者主觀認定的狀況，事實上，個別駕駛人主觀認知皆會影響其注意力分配之策略，面對相同行車環境與潛在威脅衝突，不同族群之駕駛人可能產生相異的認知風險，導致迥異的注意力分配，後續實證分析必須針對此一輸入變數進行調查。

伍、結論

了解事故原貌為道路交通事故預防的重要關鍵，過去許多研究應用道路事故總體性資料進行分析，企圖解構事故發生的前因後果，挖掘影響事故發生、型態與嚴重度的因素，然而此等研究多僅針對相關影響因素對於事故之影響，並藉以建構高風險事故情境，解釋事故發生的所在環境與外顯的過程，但卻無法真正解釋為什麼事故會發生；每一天無數車輛、駕駛人行車經過易肇事路段，然而始終僅有極少數的個案發生會導致事故發生的結果，顯見擷取事故的影響因素並不足以揭露事故原貌。人為因素為道路交通事故最重要的影響因素，鑒於過去事故總體資料分析對事故鏈與事故全貌解釋之不足，本研究嘗試以駕駛人心智負荷分析之方式，藉由駕駛工作需求與心智能力之互動，探討個別駕駛人於不同情境下之決策行為，以及行為所衍伸之心智狀態與後續事故風險，也唯有更深入探討駕駛人心智程序，探討駕駛過程當中，駕駛人如何利用其有限的心智資源，方能補足高風險情境與事故發生之間尚未能充分解釋之失落環節。

駕駛為即時資訊接收與分析之連續性過程，即時、完善的資訊提供，可幫助駕駛人在正確的時間與地點，進行合宜的決策，採取適當的行動，降低事故發生的風險。然而，並非所有的資訊對行車安全都具備有正面的效果，過多的資訊量、不當的資訊給定型式或不當的資訊給定時間、地點，都有可能對行車安全造成負面的效果，而且不同駕駛族群對安全資訊的要求不一定相同。因此，如何善用日新月異的智慧型運輸系統與相關科技，以更有組織的方式將各類安全資訊整理出來，並在合適的時間、合適的地點以及適當的情況下，針對不同駕駛人的特性，有效的提供合適之安全資訊，以及了解此等安全資訊的績效即成為一個非常重要且值得深入研究的課題。

「即時安全資訊系統之建構、分析與應用」為三年期之研究計畫，目的在於建立完整的即時安全資訊系統架構，透過架構之建立，分析即時安全資訊系統之需求，提供客製化安全資訊，並衡量即時安全資訊系統之績效。於第一年度之研究階段，本研究以駕駛人心智負荷量為題，建構駕駛心智模式之研究架構，本年

度進一步針對駕駛工作進行分析，透過注意力需求函數反應多重安全威脅與多重平行工作帶給駕駛人的工作量，並藉由注意力分配模式之建立，了解駕駛人將有限心智資源分配至多個安全威脅的策略，以接收完整駕駛資訊供後續行車操作之用。

本研究應用個體選擇模式，納入認知風險、定向反應與行車資訊取得等三大類影響注意力焦點選擇機率的變數，建構駕駛注意力分配模式。由模式經校估所得之注意力分配機率，研究者得以探討駕駛人為求最小化認知風險的衝擊，在特定狀況下分配注意力之策略與機制，同時探討外界行車資訊對注意力分配的衝擊。本階段之研究提出模式架構與重要變數，後續將持續進行實證資料收集與模式參數校估。以注意力分配模式為基礎，後續研究得以進一步探討即時安全資訊的提供對駕駛人注意力分配之衝擊。

陸、後續研究架構

1. 實驗設計與模式校估

本年度研究提出注意力分配模式之架構與重要輸入變數，下一年度將著重於透過收集資料與實證分析，以進行模式參數校估以及後續於行車安全資訊提供之應用。

以本階段所提出之注意力分配模式架構為基礎，實驗將採實車方式進行，透過監控駕駛人於行車過程中視線的轉移，並同時收集道路駕駛環境中各個行車安全威脅之動態，以匯入模式探討駕駛人注意力分配之策略。鑒於前階段所歸納之 24 個注意力焦點選擇方案過於複雜，為簡化操作，本研究於實證階段將駕駛情境設定於雙車道且禁行機車路段，此外，並將注意力焦點選擇方案減少至 13 個方案，包含：

(1) 認知領域前方區域 ($T_{1,1}$)
(2) 觸發反應領域正前方車道 ($T_{2,1}$)
(3) 觸發反應領域前方鄰近車道 ($T_{2,3}$)
(4) 臨界領域正前方車道 ($T_{3,1}$)
(5) 臨界領域前方鄰近車道 ($T_{3,3}$)
(6) 觸發反應領域後方鄰近車道 ($T_{2,4}$)
(7) 臨界領域後方鄰近車道 ($T_{3,4}$)
(8) 正後方車道 ($T_{3,2}$)
(9) 位於認知領域之行車資訊 ($I_{1,1}$)
(10) 位於觸發反應領域之路側行車資訊 ($I_{2,1}$)
(11) 位於觸發反應領域之路中行車資訊 ($I_{2,2}$)
(12) 位於臨界領域之路側行車資訊 ($I_{3,1}$)
(13) 位於臨界領域之路中行車資訊 ($I_{3,2}$)

實驗資料收集主要仰賴眼動儀以記錄駕駛人眼球移動並將視線焦點對應至視線所及範圍之影響，如圖 10 所視，眼動儀可在不影響正常行車操作下，同時追蹤眼球移動並攝錄視線所及範圍，加以比對後可由圖像方式呈現駕駛人於各個瞬間的注意力焦點所在，本研究將應用此一技術，自駕駛人持續性的駕駛操作特性擷取模式之輸入資料。此外，眼球在日常生活中會不斷快速跳動，在每次跳動之間會有短暫停留，認知心理領域與腦神經科學相關研究顯示，僅有在眼球短暫停留的瞬間 (一般認為每 1/4 秒可完成一次視線移轉與資料收集) 才能接收資訊 (鄭麗玉，2009)；基於此一假設，本研究可將眼動儀所收集之影響分為兩類型的資料進行處理，首先為駕駛人移轉注意力 (眼球跳動) 至其它焦點的過程可被視為一筆注意力焦點選擇之樣本，此外，當駕駛人長時間注視某一焦點時 (超過 1/4 秒以上)，則須將該時段以每秒四個樣本的頻率進行切割，換言之，長時間注視同一焦點應被視為駕駛人連續選擇同一區域或物體作為注意力焦點。

資料來源：皮托科技網站 (2010)

圖 10 眼動儀於駕駛注意力分配之應用

透過眼動儀，本研究得以收集下列資料：行車安全威脅所在車輛領域、行車安全威脅所在位置、行車安全威脅操作、行車安全威脅特性 (新奇性、複雜性)、行車安全資訊所在車輛領域、行車安全資訊所在位置、行車安全資訊內容型態等，資料收集與輸入格式如表 5 所示。表 5 內容顯示在駕駛人的短期記憶內共有兩個安全威脅存在於駕駛環境當中，其中位於認知領域前方區域的車輛正維持執行 ($T_{1,1,1}$ = 1)，鄰近車道上位於觸發安全領域內的車輛則正在變換車道 ($T_{2,3,4}$ = 1)，該車同時具有複雜威脅的特性 ($Co_{2,3}$ = 1)，此外，駕駛人亦發現觸發領域的路側有一文字標誌 ($Te_{2,2} = I_{2,2} = 1$)，綜合以上短期記憶與分配策略，最後駕駛人選擇將注意力視線維持在觸發安全領域的鄰近車道 ($F_{2,3}$ = 1)，接著再進行下一階段的注意力分配與資訊接收。以圖 9 為基礎，上述資料可進一步歸納整合為認知風險水準評估、定向反應、行車資訊收集等三大類決策變數，後續並將上述決策變數匯入注意力分配模式進行參數校估。

表 5 資料輸入範例

編號	安全威脅所在位置								行車資訊所在位置				
	$T_{1,1,k}$	$T_{2,1,k}$	$T_{2,3,k}$	$T_{3,1,k}$	$T_{3,3,k}$	$T_{2,4,k}$	$T_{3,4,k}$	$T_{3,2,k}$	$I_{1,1}$	$I_{2,1}$	$I_{2,2}$	$I_{3,1}$	$I_{3,2}$
	$k=1$	0	4	0	0	0	0	0	0	0	1	0	0
	狀態改變								行車資訊是否已辨識				
	$Sc_{1,1}$	$Sc_{2,1}$	$Sc_{2,3}$	$Sc_{3,1}$	$Sc_{3,3}$	$Sc_{2,4}$	$Sc_{3,4}$	$Sc_{3,2}$	$Id_{1,1}$	$Id_{2,1}$	$Id_{2,2}$	$Id_{3,1}$	$Id_{3,2}$
	0	0	0	0	0	0	0	0	0	0	0	0	0
	複雜威脅								行車資訊呈現方式				
	$Co_{1,1}$	$Co_{2,1}$	$Co_{2,3}$	$Co_{3,1}$	$Co_{3,3}$	$Co_{2,4}$	$Co_{3,4}$	$Co_{3,2}$	$Te_{1,1}$	$Te_{2,1}$	$Te_{2,2}$	$Te_{3,1}$	$Te_{3,2}$
	0	0	1	0	0	0	0	0	0	0	1	0	0
	新奇威脅												
	$N_{1,1}$	$N_{2,1}$	$N_{2,3}$	$N_{3,1}$	$N_{3,3}$	$N_{2,4}$	$N_{3,4}$	$N_{3,2}$					
	0	0	0	0	0	0	0	0					
	選擇注意力焦點												
	$F'_{1,1}$	$F'_{2,1}$	$F'_{2,3}$	$F'_{3,1}$	$F'_{3,3}$	$F'_{2,4}$	$F'_{3,4}$	$F'_{3,2}$	$f'_{1,1}$	$f'_{2,1}$	$f'_{2,2}$	$f'_{3,1}$	$f'_{3,2}$
	0	0	1	0	0	0	0	0	0	0	0	0	0

實驗與資料收集分為兩階段，以及各階段內兩個不同的駕駛工作，第一階段為模擬駕駛人對於道路駕駛環境不熟悉之狀態，於此階段，受測者被告知行車路徑，並要求駕駛人在經過特定地點後應嘗試變換車道，除此之外並未提供任何關於道路駕駛環境之任何訊息；透過此階段之情境設定，受測者在行車過程中必須持續搜尋變換車道的指示，藉以模擬駕駛人在不熟悉路況的情境下必須同時分配注意力在駕駛工作與行車資訊收集；第二階段要求受測者重新行駛前一階段所設定之路徑，此情境可假設受測者對道路駕駛環境已具有相當程度之熟悉。經過上述兩階段實驗後，研究可得駕駛人在直行與變換車道兩行車操作下的注意力分配過程，此外，透過擷取駕駛過程當中的靜態影像，本研究另要求受測者針對位處不同領域、相對位置以及採取不同操作行為之車輛回答其主觀認知風險水準 (如表 1 至表 3)，以作為模式校估之輸入資料。

本研究應用多項羅吉特模式作為注意力分配模式建構之用，透過模式之建構，本研究得以分析下述議題：1) 探討於不同行車操作下的注意力策略，本研究主要探討維持直行與變換車道兩行車操作，透過參數校估結果得以比較駕駛人在不同的行為意向之下，注意力集中範圍的差異；2) 本研究納入前階段注意力焦點作為決策變數之一，藉由此一變數可呈現駕駛人在不同行車操作之下，注意力焦點移轉的順序與趨勢；3) 探討駕駛人熟悉度是否會對行車資訊的基礎注意力產生影響。基於注意力分配模式之構建，本研究得以做為分析行車資訊對駕駛安全之淨效果。

2. 定位基礎安全資訊服務

隨著智慧型運輸系統相關技術發展，駕駛人得以更簡單地取得即時交通相關資藉以加強安全駕駛，然而每位駕駛對於駕駛資訊需求不同，資訊提供對於駕駛人注意力分配與心智負荷亦可能產生不同程度的影響。因此，在提供駕駛人相關

資訊前必須先從心智能力與駕駛需求的角度，了解相關資訊對於駕駛安全之淨效果。

從使用者的角度而言，駕駛人認為資訊的提供在駕駛過程中可以幫助決策以降低工作需求 (Brookhuis and de Waard，1999；Creaser *et al.*，2007)，諸如天氣、車流、路況、事故等即時資訊可降低駕駛不確定性，幫助駕駛人提前分配心智資源以面對可能發生的事件。駕駛人對於外在刺激的主動反應得以避免突發事件的發生，相關研究亦顯示，資訊提供與主動反應可有效降低駕駛人心智負荷 (Fuller，2005；Verway，2000)。然而資訊的提供亦會產生諸如分心與情境察覺能力退化等負面效應，雖然駕駛人在資訊產生負面效應且可能危及安全時，通常會採取相關的補償策略，藉以降低次要作業產生的衝擊，並盡可能在駕駛工作上維持較高水準的注意力與心智資源投入，然而研究亦顯示，駕駛人常會錯估其駕駛能力與外在資訊的衝擊，進而導致低估風險並做出錯誤的決策，以使用行動電話為例，駕駛人若使用手持行動電話時會降低車速並增加行車間距，然而使用免持聽筒時則否，即使兩者產生的分心效應相當 (Caird *et al.*，2008；Liu and Lee，2005a；2005b；Nunes and Recarte，2002；Patten *et al.*，2004；Törnros and Bolling，2006)。

手機通訊對駕駛人會產生注意力錯誤分配之負面效應，行車安全資訊亦然。駕駛資訊之提供並非有百利而無一害，唯有在適當時機、地點提供適切的資訊給正確的駕駛才能有效降低事故風險 (Wong and Chung，2007a)，資訊使用不當反而會造成駕駛安全的負面效應。Elvik (2006) 所提出之複雜度法則指出，事故風險會隨著駕駛人在單位時間內接受資訊量增加而提升，當身處在具有大量資訊匯入的環境之中，駕駛人非但無法取得重要資訊，反而可能因分心與資訊負載過量造成更嚴重的事故風險；此外，Pelmets 效應亦指出，即使資訊之提供可造成行車安全正面之效益，但是駕駛人可能因為資訊提供而導致其他高風險駕駛行為的產生 (Peltzman，1975)，是故，完整的安全資訊系統必須將資訊副作用納入，藉以最佳化智慧型運輸系統以及其他資訊提供媒介的使用，以提升其對駕駛安全的正面助益 (Verway，2000)。

本研究提出注意力分配模式之概念，提供作為行車安全資訊分析之工具與平台，探討資訊提供對於駕駛熟悉度與注意力分配之衝擊；於第三年度，本研究亦將提出「定位基礎安全資訊服務」之概念，結合注意力分配模式，最佳化行車安全資訊，並降低資訊提供帶來的負面衝擊。

行車安全資訊主要可分為下列三種類型與兩種傳遞方式：

(1) 行車輔助型

行車輔助資訊主要包含路徑導引、車流狀況、相關行車規範等，其目的在於增進駕駛人對於駕駛環境的了解與掌握度，就使用者的角度而言，駕駛

人認為越多的資訊越能幫助做出正確的決策，並且最佳化駕駛工作與心智資源的分配 (Brookhuis and de Waard，1999；Creaser *et al.*，2007)，此外，給予駕駛人適當之行車輔助系統得以幫助判斷其將面對之交通狀況，以預先採取相關策略並主動因應，使注意力得以預先分配至適當之活動，降低潛在之事故風險 (Fuller，2005；Verway，2000)。

部份行車輔助資訊得以在行前事先規劃，同時間，透過車內資訊系統與行中的可變資訊標誌亦可即時提供相關訊息。可變資訊標誌係針對特定區域或狀況下，提供適切之行車資訊，例如在人口聚集地顯示停車場資訊、高速公路顯示壅塞路段等，唯該資訊之提供對象為一般大眾，資訊內容雖已針對特定情境加以設計，然而仍未能針對個別駕駛人進行提供。Al-Ghamdi (2007) 透過濃霧偵測與警告標誌之設立，討論駕駛人對於可變資訊標誌系統之接受度，研究顯示，針對特定狀況 (該研究係針對濃霧狀況) 所提供之資訊將顯著改變駕駛人的行車操作；此外，部份研究以路口決策支援 (Intersection Decision Support，IDS) 系統為題，探討可變標誌系統之應用，藉由偵測即時車流狀況，IDS 系統得以提供駕駛人建議，幫助駕駛人選擇通過路口之最佳時機 (Creaser *et al.*，2007； Laberge *et al.*，2006)。

如同前述，可變標誌雖能針對特定路況進行資訊傳遞，然而無法顧及個別駕駛人的資訊需求，車內資訊系統可進一步提供諸如易肇事路段、路徑導引、天候、路況報導等客製化之行車輔助資訊，以滿足不同駕駛人在不同狀況下的獨特需求。車內資訊系統之應用可更有效的增加駕駛人對於行車的掌控度，藉以提早改變路徑或行車計畫，即便駕駛人無法改變策略，在面對惡劣交通條件 (例如惡劣天候狀況或塞車等)，車內資訊系統仍可提供諸如目前車速、預估旅行時間、尚須多久時間方可脫離車陣等資訊，幫助駕駛人掌握目前狀態，降低感受到之沮喪與挫折，避免因負面情緒而造成注意力錯誤配置 (van Driel *et al.*，2007)。除此之外，車內資訊系統更可在緊急狀況下提供駕駛人相關協助與指示，Vashitz *et al.* (2008) 以長隧道為例，透過車內資訊系統提供駕駛人一般性的車流資訊以及緊急狀況的逃生指示，該系統在隧道內發生火災時，會指示駕駛人最近的逃生地點，以爭取避難時效。

過去多數研究顯示駕駛人偏好自各種資訊源取得即時資訊，並且認為即時資訊的取得對行車安全有正向之幫助，然而此等資訊於收集過程中必須移轉駕駛人原分配在駕駛工作上的注意力，分心的結果可能造成事故風險增加；此外，適當的資訊提供位置、方式必須進行妥善設計，錯誤的即時資訊不但無法幫助駕駛人，反而會導致駕駛人必須分心理解無用的訊息。

(2) 警告型資訊

警告型資訊的主要目的為幫助駕駛人偵測潛在之行車風險，藉以加強情境察覺能力，避免行車安全盲點的威脅。透過偵測與監控的技術，警告型資

訊系統得以辨識可能危及安全的物體車輛，確保駕駛人得以察覺相關風險，並降低搜尋潛在安全威脅的工作量。

車輛防撞警示系統 (Vehicle collision warning system，CWS) 透過車載的偵測器搜尋道路上的障礙物，並且量測該行車威脅與駕駛人之間的距離，當系統所設定的安全範圍內出現安全威脅，系統將警告駕駛人並提供相關操作建議 (Kumar *et al.*，2005；Maltz and Shinar，2007；Shaheen and Niemeier，2001；Tan and Huang，2006；Vahidi and Eskandarian，2003)。近年來，互動式車輛防撞系統 (Cooperative collision warning system，CCWS) 之概念已逐漸受到重視，不同於傳統 CWS 僅由車輛上的單向偵測器提供資訊，互動式車輛防撞系統之概念仰賴車輛之間的通訊功能，若道路上的所有車輛皆裝有相關的定位與通訊設備，偵測並傳遞本身的車速、行向、加減速度等，透過該系統之定位得以判斷鄰近區域內所有車輛的位置，並且針對該特定範圍內的所有車輛建議最佳的行車操作 (Polychronopoulos *et al.*，2007；Tan and Huang，2006)。然而此一互動式的防撞系統於發展上仍有困難必須突破，並非所有車輛都配備有互動與偵測設備，道路上任一未配備互動防撞系統之車輛即為資訊傳遞與防撞偵測的黑洞 (Tan and Huang，2006)。

除了上述針對存在於周遭環境的安全威脅，警告型資訊系統亦可偵測駕駛人的行車動態，在可能產生危險狀況時提供警訊，以速度控制為例，於行車過程當中，駕駛人必須頻繁的檢視儀表板與路旁速限標誌，以確認行車速度並未超過規定，自動速度偵測與警示系統可透過 GPS 定位或路側設施取得該路段之速限資訊，當駕駛人車速超過速限時則可給予警告 (Marell and Westin，1999；Young and Regan，2007)。此外，為避免駕駛人因過多外界環境刺激而導致分心，車內警告性資訊系統透過追蹤駕駛人眼球或頭部轉動，判斷駕駛人於單位時間內的分心狀態，若駕駛人花費過多時間在掃視非駕駛相關區域時，系統可警告駕駛人已出現分心狀況，並回饋至車內資訊系統以調整資訊內容 (Donmez *et al.*，2007)。

(3) 自動化操控型資訊

自動化操控資訊屬於行車資訊系統的強制性介入，藉以避免人為誤失對行車安全造成傷害，安全防護資訊的主要功能包含車輛的自動控制以及限制危險駕駛行為。

自動化公路 (Automated highway system，AHS) 之目標為達成駕駛人完全無須主動採取任何行為操作的自動駕駛，其核心技術為先進車輛控制系統 (Advance vehicle control system，AVC)，包含透過適應性巡航系統 (Adapted cruise control，ACC) 控制速度與行車方向 (Young and Regan，2007)，藉由強制介入車輛操作，自動化公路可降低車流速度的變異，並且限制超車、變換車道等行為，藉以提升行車安全與公路容量 (Carbaugh *et al.*，1998；Vahidi and Eskandarian，2003；Young and Regan，2007)。

前段所述之警告型資訊系統亦可加入自動化控制之功能。例如智慧型速度控制 (Intelligent Speed Adapter，ISA) 不僅能在超速時提供警示，更可自動切斷油門避免駕駛人超速 (Molin and Brookhuis，2007；Young and Regan，2007)。變換車道支援系統 (Emergency Lane Assists，ELA) 則可透過偵測周圍環境的車流狀況，當駕駛人欲在危險狀態下變換車道時，系統會產生一逆向的力矩，將車輛導回原行駛車道 (Eidehall，2007)。此外，考量到駕駛人在使用資訊系統或行動通訊時，往往低估其分心帶來的風險，車內通訊管理系統在駕駛人處於高負荷狀態下時，會限制行動通訊或車內資訊系統之使用，以避免駕駛人分心造成事故發生 (Bruyas *et al.*，2009；Nunes and Recarte，2002；Piechulla *et al.*，2003)。

在理想狀態下，自動化系統的運作可使行車過程完全不會受到人為因素所干擾，駕駛人僅需耗費心力在監控系統的正常運作；然而自動化系統的應用取決於駕駛人的接受度。過去研究顯示，一般駕駛人對於智慧型運輸系統的接受度極高，其中唯有自動化系統的使用率偏低；此類自動化系統剝奪駕駛人對車輛的主控權，因此駕駛人偏向使用提供資訊或警示功能的資訊系統，而非自動化操控系統 (Al-Ghamdi，2007；Bruyas *et al.*，2009；Donmez *et al.*，2007；Marell and Westin，1999；Molin and Brookhuis，2007；Vashitz *et al.*，2008；van Driel *et al.*，2007；Young and Regan，2007)。

(4) 資訊傳遞媒介 (聽覺與視覺)

資訊的提供方式主要可分為視覺與聽覺兩類，不同的資訊傳遞媒介會產生不同的效果，並適用於不同類型的行車資訊。視覺資訊通常被使用在諸如路徑導引之類的行車輔助型資訊系統，行車過程當中，道路環境當中絕大多數的安全威脅必須倚靠視覺搜尋，因此，透過視覺化的表達方式可能造成的分心風險遠大於其他媒介 (Hatfield and Chamberlain，2008)；為降低衝擊，若採用視覺化的平台呈現行車資訊必須考量置放資訊源的位置，根據研究，駕駛人的中央視野區域 (儀表板附近) 為造成最小分心的位置 (Neale *et al.*，2007)。對於警告型資訊而言，考量到安全警示並非持續性的資訊，駕駛人不可能將視覺注意力隨時分配至車內資訊系統，藉以觀察是否有警告訊息出現，此外，與其專心於觀察車內資訊系統，駕駛人寧願將注意力投注在道路駕駛環境當中，藉以觀察潛在威脅 (Maltz and Shinar，2007；Neale *et al.*，2007)；因此，縱使聽覺資訊可提供較少的資訊量，警告型資訊系統仍適用以聽覺方式傳遞資訊 (Maltz and Shinar，2007)。

於現行的行車資訊系統，多數資訊仍須仰賴駕駛人的主動搜尋，未能達到完全的客製化；以下的情境為完成一次行車的過程當中，駕駛人可能面臨的情境，以及其得以收集的資訊內容與方法。出發前，駕駛人可以上網查詢最新的路況資訊，透過路徑規畫軟體研擬最短路徑，並依據過去經驗 (例如經常塞車的時段與路段) 調整規劃的路徑，最後將資訊輸入長期記憶或車內導航設施；出發後，駕駛人必須持續將注意力分配至駕駛環境當中的每個安全威脅，同時間，駕駛人必須注意路旁的路名標誌，並與車內導航設施或長期記憶裡所儲存的規劃路徑做比較，確認行駛路線是否正確；出發一段時間後，駕駛人發現進入非預期的擁擠車流，由於不知前方狀況，無法確定車陣長度以及預估疏散時間，駕駛人開始煩躁，且嘗試頻繁變換車道，同時間駕駛人打開廣播，期望從路況報導嘗試理解車流狀況；當廣播開始報導最新路況時，駕駛人發現前方發生嚴重車禍，且預期必須花費較長時間才能通過壅塞路段，因此，駕駛人必須使用車內導航設施或是依據過去經驗開始研擬替代路徑；在完成替代路徑規劃後，駕駛人開始尋找適當時機變換車道以離開壅塞路段，由於已在車陣中浪費些許時間，為加以補償，駕駛人選擇較高速行駛，但為避免超速被舉發，行車同時必須時時注意儀表板、路旁速限標誌，以維持行駛於合理範圍內。

上述情境內提及數個在收集資訊同時可能帶來的安全風險；首先駕駛人雖然得已事先規劃行車路徑，然而道路交通狀況隨時都在變化，於行駛過程中往往會碰到突發狀況而導致行車受到影響，然而一般路況報導僅能提供區域性之路況，多數資訊與駕駛人行駛路徑無關，導致駕駛人不一定能及早發現前方路況；此外，即便駕駛人主動透過廣播或其他方式搜尋路況資訊，其於駕駛過程當中可能造成嚴重的分心，尤其當廣播或其他媒介正在提供與目前狀況相關的訊息時，駕駛人注意力將大幅轉移至該資訊，而增加與其他車輛碰撞之機會；路徑規劃為一繁瑣之作業，駕駛人必須設定起訖點，等待系統進行規劃，並理解規劃後的路徑，此過程若發生於行車途中，駕駛人不但必須將視線移轉至該系統，同時必須動手輸入相關設定，此一行為將嚴重威脅行車安全。由此一情境說明可發現，現今資訊系統尚未達到客製化、即時與需求導向之水準，駕駛人仍必須主動搜尋或等待、過濾適用之資訊，此一動作於行車過程當中即有可能造成過度分心，並錯失避免事故發生的關鍵時機；因此，本研究於下階段將提出一需求導向的「定位基礎安全資訊服務 (Location based safety information service)」，藉由連結各大行車資訊資料庫、行車偵測器與 GPS 定位系統，車內資訊系統得以根據目前所在位置以及行車動態提供最適切之資訊。

定位基礎安全資訊服務為一整合性的行車資訊系統，有別於過去透過 ITS 技術或其他靜態資訊源傳遞資訊，定位基礎安全資訊服務整合駕駛人所需之資訊，並以適時、適地為原則，傳遞適切之資訊予駕駛人。定位基礎安全資訊服務與傳統行車資訊系統之比較如下述四點，定位基礎資訊系統之概念如圖 11。

(1) 總體資訊 VS. 個體化需求導向資訊

過去資訊多未能提供客製化之內容，導致駕駛人必須自大量資訊中篩選可用的訊息，此外，資訊提供的時機亦無法反映駕駛人的需求，例如廣播路況並非隨時隨地，駕駛人必須等待路況報導時段方能取得相關資訊；定位基礎安全資訊服務則是透過定位系統與行車感應器偵測周圍車流，判斷駕駛人需求，藉以在適當時機提供適當資訊。

(2) 駕駛人主動搜尋資訊 VS. 系統主動提供資訊

傳統行車資訊系統仍須由駕駛人主動透過視覺、聽覺等方式搜尋，亦或是在行車途中必須進行操作以查詢相關資訊，此一類型資訊將導致駕駛人於駕駛過程當中產生分心狀況；定位基礎安全資訊服務則是依時依地判斷駕駛人之需求，並主動提供資訊予駕駛人。

(3) 單向資訊 VS. 互動系統

過去行車資訊系統僅能單向提供訊息，無法針對駕駛人的需求與反應加以調整；定位基礎安全資訊服務則是容許系統與周圍環境車流、駕駛人狀態等互動，當環境存在安全威脅須要駕駛人排除時，系統則會避免提供資訊造成駕駛人分心。

(4) 仰賴長期記憶 VS. 使用短期記憶

部份行車資訊必須在行前進行收集，駕駛人必須將所收集資訊存入長期記憶，或是透過紙筆等方式記錄，待需要時再進行提取使用，然而長期記憶須耗費較多時間進行處理，資訊內容亦常錯誤或遺忘；定位基礎安全資訊服務僅在適當的時機提供即時資訊，駕駛人可將之存入短期記憶並快速提取，當使用完畢後即可自短期記憶內移除。

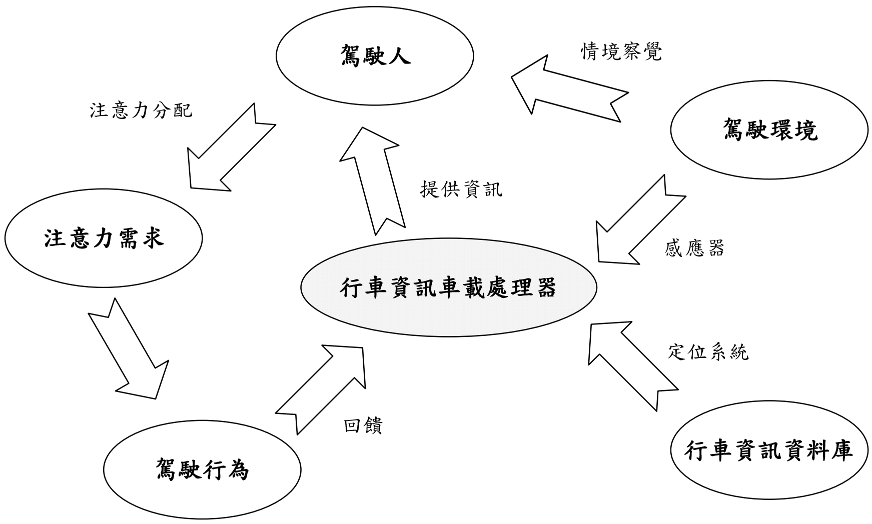

圖 11 定位基礎安全資訊服務架構

如圖 11，定位基礎安全資訊服務主要收集並提供兩類型資訊，首先透過感應器偵測道路環境內的安全威脅，當設定之範圍內出現車輛或其他物體時，警示駕駛人應採取行動，此一範圍應介於觸發反應領域與關鍵領域之間，以給予駕駛人足夠時間加以理解與決策。第二類資訊為結合 GPS 定位系統與行車資訊資料庫，將駕駛人行駛區域以及未來規劃之路徑的相關資訊提供給駕駛人，包含事故地點、危險路段、車流壅塞路段、施工地點、速限等，當駕駛人出現特定行為或行經特定地點時，觸發對應之資訊給駕駛人，例如當行經限制超車或常因變換車道發生車禍之地點時，若駕駛人打方向燈或改變行向則可提示駕駛人該路段之行車風險。外界資料輸入至車載資訊處理器後，系統得以在適當時機提供給駕駛人，同時，駕駛人必須持續進行注意力分配以維持駕駛安全，若系統偵測駕駛人分心程度 (眼球掃視頻率) 或駕駛工作量 (鄰近安全威脅位置與操作) 過高時，系統則暫停其他資訊，僅提供相關的警示予駕駛人。

定位基礎安全資訊服務的引進改變行車資訊的傳遞與使用，透過即時性與需求導向的資訊可免除前述駕駛人搜尋資訊情境中所增加之行車風險。上述情境在定位基礎安全資訊服務的引入後可改寫如下：駕駛人於出發前可於系統設定起訖點，依據目前路況、重現性交通特性、駕駛人偏好等設定，系統可規劃適合之路徑供駕駛人參考；出發後，車內資訊系統會隨時偵測車輛定位，確認駕駛人是否維持在設定之路徑上，同時系統亦會持續查詢規劃路徑上路況資訊，當前方有事故或狀況時即早通知駕駛人，若有壅塞車流則會重新規劃路徑，並在駕駛人得以接收資訊時 (例如等紅燈) 將更新後之路徑資訊告知駕駛人。於行車過程中，系統會持續偵測鄰近道路區域與車輛行駛動態，當發現可能危及安全之威脅或駕駛人採取超速等高風險駕駛行為時，系統將給予警示，提醒駕駛人注意。透過上述情境之呈現，定位基礎安全資訊服務可幫助駕駛人在安全的前提下，更有效率的提供行車資訊，以增進行車安全。

資訊可為行車安全帶來正面影響，包含調整注意力分配策略與增加對道路駕駛環境的熟悉度，然而同時亦會帶來分心的負面影響，本研究於第二年期所提出之注意力分配模式為評價行車資訊優劣的工具，對行車安全有正向幫助的資訊理應增加駕駛人的熟悉度，降低主動搜尋資訊的基礎注意力，以保留足夠之心智資源於駕駛作業上。透過本模式，研究得以評估行車資訊的淨效果，並藉以提供最適切的行車資訊系統。

3. 未來工作項目

過去對於行車資訊系統之探討多僅針對單一功能與總體化資訊，未能顧及個別駕駛人於不同狀況下之需求，以第二年期所提出之注意力分配模式為基礎，本研究於第三年期將進一步提出「定位基礎安全資訊服務」之概念，結合車載資訊處理器、感應器與定位系統等技術，在適當的時間、地點提供正確之資訊，並藉

以降低資訊提供造成之負面效應。

後續工作項目概述如下：

(1) 資料收集與注意力分配模式參數校估

本研究於第二年期計畫已提出注意力分配模式之架構與重要決策變數，於下一階段應進行實驗與資料收集，藉以校估其中參數，並探討在不同情境下之注意力分配策略。

- 實驗設計
- 歸納重要之駕駛情境，並調查駕駛人於該情境之認知風險水準
- 追蹤並記錄駕駛人於行車過程中，注意力焦點之移轉
- 注意力分配模式參數校估
- 歸納駕駛人於各情境之注意力分配策略

(2) 定位基礎安全資訊服務建立

為探討安全資訊的應用，本研究提出定位基礎安全資訊服務之概念，藉由通訊、偵測、資料庫等科技之整合，在適當地點與時間提供駕駛人正確之資訊，並以前階段建立之注意力分配模式，評估提供特定行車資訊之淨效果。

- 彙整行車安全資訊之來源、內容與媒介
- 建立行車安全資訊之觸發規則
- 實驗設計
- 建立注意力分配模式以探討資訊對行車安全之淨效果

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Modeling Driver Mental Workload for Accident Causation and Prevention

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Abstract: Past road safety studies have mostly focused on the identification of scenarios involving high accident risk. However, risky scenarios can only describe accident outcomes rather than the real causality. Discussion of driver's cognitive interaction while driving is a necessity for deeper exploration about the nature of accident. To comprehend the entire structure of mental workload, this research proposes a research framework for studying mental models that incorporates task demand and motivated capability. Understanding the contributing factors of mental model and the individual difference in task demand and motivated capability can help evaluate the mental workload. In addition, integrating mental model with accident chain analysis enables exploring information net effect on mental workload. Thus, optimized information can hopefully be defined and provided to drivers in different scenarios without causing additional risk of accidents.

Key Words: *mental workload, information, task demand, motivated capability*

1. INTRODUCTION

Accident predictability has long been controversial. Bortkiewicz, usually considered the pioneer of modern accident research, said in an 1898 study that accidents are random and thus inexplicable (Elvik, 2006). However, the development of modern analysis techniques has inspired various attempts to explore the causality of accidents. Numerous contributing factors have been found critical to roadway safety. For example, rear-end accidents increased with the number of signal phases and width of traffic island (Chin and Quddus, 2003). Demographic characteristics such as age and gender also have been extensively studied (Chang and Yeh, 2007; Clarke *et al.*, 1998a; Clarke *et al.*, 1998b). That is, in addition to the contributing factors which are closest to accident, certain remote factors also have been seriously considered (Verschuur and Hurts, 2008; Wong and Chung, 2007a; 2007b). Recent research has further claimed that accidents should be analyzed from a chain perspective. For example, personality traits can be treated as prior-to-driving factors that affect risky driving behavior (Wong *et al.*, 2009). Therefore, to understand not only the process through which crashes occur but also possible means of avoidance, an in-depth study of accident is vital.

Most previous studies of roadway accident were based on aggregated accident information. Accident chain analysis can extract accident scenarios with specific patterns. For example, Wong and Chung (2007a) found that young and inexperienced student drivers had an increased likelihood of being involved in off-road accidents on roads with speed limits between 51 and 79 kph under normal driving conditions. The scenario above explained the conditions in which drivers have increased risk of being involved in accidents, and possibly the mechanism through which such accidents occur. However, an unanswered question remains, namely the reasons accidents occur under specific conditions. The reality is that for each accident under certain conditions, there are numerous young and inexperienced student drivers who drive under identical conditions without experiencing accidents. The question thus arises of why different individuals react differently to identical conditions, resulting in different outcomes. Answers to these questions still are implicit. Obviously, aggregated data are inadequate for answering the above questions; instead it is necessary to closely examine individual driver actions.

The most important element in accident causation is well known to be the driver, who makes the decisions that control the vehicle. To explain the mechanisms of accident causation from a driver's perspective, Elvik (2006) proposed four universal laws of accident causation, including the laws of learning, rare events, complexity and cognitive capacity. Each law not only represents phenomena associated with accidents, but also reflects critical cognitive factors that are inherent in driving process and important to the causality of driving safety.

Thus, a driver's mental process must be analyzed to comprehend how accidents occur. In particular, elements in an accident prone scenario extracted from accident chain analysis and tasks under such driving environments are the most interesting. The scenario requires the driver to perform tasks that induce mental workload and mental resource consumption. Once the mental workload reaches an unacceptable level, driving safety may suffer. That is, scenarios involving high accident risk extracted from accident chain analysis indicate that driver's mental workload could be in a critical condition.

Regarding the driving tasks, advanced in-vehicle instruments further complicate the issue. Distraction by in-vehicle instruments may create additional task activities and thus decrease the spare capacity available for driving tasks (Horberry *et al.*, 2006a). Although some instruments, such as navigation systems, can help drivers allocate mental resources in advance by providing real-time information (Fuller, 2005; Verway, 2000), such devices also can increase workload and threaten safety during information acquisition. An in-depth discussion of the mental process involved in driving can help understand the impact of information on mental workload and clarify the net safety effect of ITS systems.

Workload, defined as the resources consumed in achieving a certain level of performance in tasks with specific activities and driver's capability (Hart and Staveland, 1988), is a critical indicator of driving safety. Drivers can be assumed to be more likely to encounter risky situations if the workload incurred from tasks exceeds a critical level. The workload mentioned includes physical and mental concepts. Since driving is not strength intensive, physical impairment does not seem to degrade driving performance (Elvik, 2006). DiDomenico and Nussbaum (2008) also suggested that no significant interaction exists between physical and mental workload. Consequently, this study focuses only on the mental workload issues.

Mental workload is a multifaceted issue that is critical to road safety. To understand the nature of accidents and mental workload, this study discusses issues of accident chain from the perspective of individual mental process. Section 2 analyzes the driving process from a mental perspective and identifies the critical issues to be addressed in this study. In section 3, following a critical review of related studies, a research framework is established for examining mental workload. Section 4 then discusses the issue of optimum mental workload and strategies for dealing with different levels of mental workload. Subsequently, section 5 discusses the impact of ITS safety techniques on mental workload. Finally, an issue discussion and concluding remarks are presented.

2. DRIVING MENTAL PROCESS

Considering the interaction among mental workload related factors, a conceptual framework for driving mental process is illustrated in Figure 1. The mental process of driving broadly comprises three main stages, including task activity formation, interaction between task activities and motivated capability, and maneuvering against mental workload level.

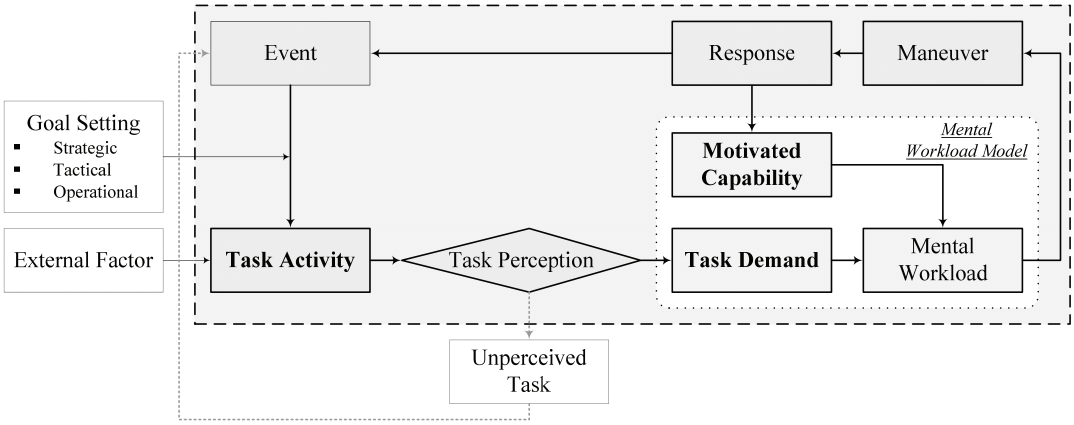


Figure 1 Conceptual framework of driving mental process

Forming driving task activities is event oriented. Here events, such as incoming phone call or traffic flows becoming congested, refer to everything that happens within the driving process that would influence the driver's behavior. To react against the events, task activities that rely on a hierarchy of goals set by the drivers are imposed and ideally must be properly undertaken. Goal setting comprises strategic, tactical and operational levels. Different levels of goal setting make different contributions to task activity triggered from the event and external factors. The strategic level of goal setting comprises knowledge based on cognitive processes which occur mostly in the pre-driving stage and are considered as remote factors affecting driving safety. The decisions, including route choice, departing and expected arrival time, or transportation mode, consist of the basic driving scenario and tasks. As for the tactical and operational levels of goal setting, both regard event recognition and related actions contribute substantially to driving behavior and task activity (de Waard, 1996; Gregersen, 2005).

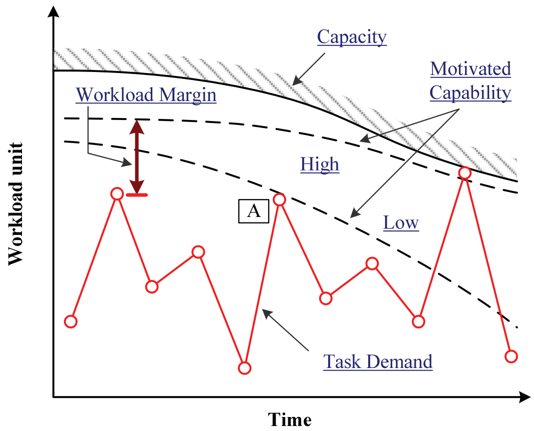
Task activity denotes the tasks that ideally would properly be performed by drivers to achieve their goals. However, not every task activity is undertaken owing to differences in vehicle control ability and situational awareness. Thus, only the task activity perceived and executed by drivers in a certain limited time interval, otherwise defined as task demand, consumes mental resources while driving. Notably, task demand or activity alone can not exhibit characteristics of mental workload. Drivers' motivated capability must also be taken into account. As shown in Figure 1, the main part of the driving mental process is the mental workload model. In which, mental workload is induced via the interaction between motivated capability and task demand.

Activities which are not perceived by drivers will not cause any task demand right at the moment. However, the gap between required task activities and the actual tasks undertaken afterwards increases the likelihood of unexpected events occurring. A larger gap indicates that drivers may be unaware that more additional work is required to achieve safe driving. Some unperceived events may immediately create other additional unexpected tasks, thus further increasing task activity and task demand. As a consequence, an accident could unfortunately occur.

3. FRAMEWORK OF MENTAL WORKLOAD MODEL

3.1 Mental Workload Model

The mental workload model comprises the linkage between perceived task demand and motivated capability of drivers. Höger *et al.* (2005) defined the mental workload model as schemas of dynamic systems or scenarios that include understanding of system components, as well as their interaction and time-dependent changes. Driver capabilities and perceived task activities vary according to conditions. Even in the same situation, different drivers may react differently, leading to different levels of mental workload. Figure 2 illustrates the mental workload model.



Source: Jex (1988)
Figure 2 Concept of mental workload model

As mentioned, each accident scenario represents a series of task activities. Even facing the same scenario, drivers with different characteristics (for example, risk-taking drivers versus average drivers) may make very different decisions, thus inducing different task demand. On the other hand, motivated capability represents the supply of mental resource in a specific condition. Due to the unique characteristics of each driver, they can have very different capabilities. External factors also may contribute to the heterogeneous nature of motivated driving capability. Briefly speaking, perceived task demand and motivated capability may differ with the driver's characteristics and other external factors.

Mental workload, shown in Figure 2, is assessed by the difference between task demand and motivated capability, which also is known as the workload margin (Jex, 1988). The level of mental workload will vary inversely proportionally with the margin (Fuller, 2005). The same task demand may have different margins under different motivated situation. Therefore, taking tasks as the only indicator of workload cannot fully describe the mental workload involved in driving. For example, point A in Figure 2 is critical in the low motivated capability condition but comparatively safe in the high motivated capability condition. An easy task can end up being difficult for drivers if their motivated capabilities are extremely low.

Macro accident data analyses can reveal the scenarios with high accident risk. However, the real causality remains unclear without deeper discussion of the differences in the reactions and behavior of individual drivers while driving. This section briefly discusses task demand, capability and mental workload model. Task demand and capability are claimed to be inconstant due to the differences in driver personal characteristics and external influences. Additionally, the transformation process from workload margin to mental workload may differ among drivers. Even given the same level of mental workload, dissimilarity in sensitivity to mental workload also cause drivers to react differently.

Up to this point, this research has highlighted the multidimensional characteristic of the mental workload model. The key, however, will lie on a series of work on task demand, motivated capability and mental workload. Thus, it appears that improving road safety is challenging, but opportunities exist to do so either through reducing task demand or increasing motivated capability via advanced technology and innovative strategies.

3.2 Task Demand

First, the two terms of task activity and task demand must be clearly clarified. Regardless of the individual differences in situational awareness or other driving skills, task activity is an event-oriented and task-centered measurement determined by the number of simultaneous tasks that must be undertaken to realize series of goals set by drivers when facing a specific event. Task activity is triggered by expected and unexpected events. Considering the influence of external factors and the goals set by drivers, each event creates certain task activities that would be performed. Task demand, on the other hand, is human-centered and is defined as the total amount of task units executed by drivers per unit of time. Clearly, the timing to execute a task is critical for task demand analyses. Unlike event-oriented task activity, task demand will be affected by the personality characteristics and situational awareness of individuals. Different drivers with different traits may make different decisions and suffer different task demands in relation to the same task activity. Restated, task activity denotes the tasks drivers should properly undertake while task demand comprises the tasks that drivers choose to and do undertake in a certain limiting time.

For example, when approaching a work zone, a driver is likely to change his/her lane. Activities against the event include decelerating, looking in the mirror, making a turn signal and turning the wheel. To novice and inexperience drivers, they might skip the activity of looking in the mirror and turning the wheel quickly. On the other hand, to those experienced drivers, they might undertake every necessary activity and change his/her lane under a permitted traffic condition.

Task activities that have not been perceived by drivers do not cause task demand but do increase the likelihood of unexpected events that might create more serious problems. As indicated by Elvik (2006), rare and unexpected events may increase the accident risk. If drivers can accurately predict potential events in advance, tasks could be well allocated and task activity per unit of time can be maintained at a reasonably low level. On the contrary, unexpected events mostly occur comparatively quickly. Although the total task activity remains the same, the sharp increase in task activity per unit of time sometimes makes drivers unable to maintain safety. As the example of approaching a work zone, drivers who do not look in the mirrors seem to have less task demand. But if it follows with a confliction with vehicles in the adjacent lane, the ignorance can result in a sharp increase of task demand. This also suggested that permitted time for executing tasks is crucial for task demand and can have substantially meaning in driver's mental resource allocation.

Figure 3 illustrates a framework for task demand analyses. Accident data provide valuable information for analyzing task activity and task demand. Although accident data analyses do not illuminate cognitive activities associated with driving, extraction of accident prone scenarios still provides crucial clues to identify conditions in which excessive task activities must be undertaken under a certain level of capability, thus impacting driver ability to drive safely.

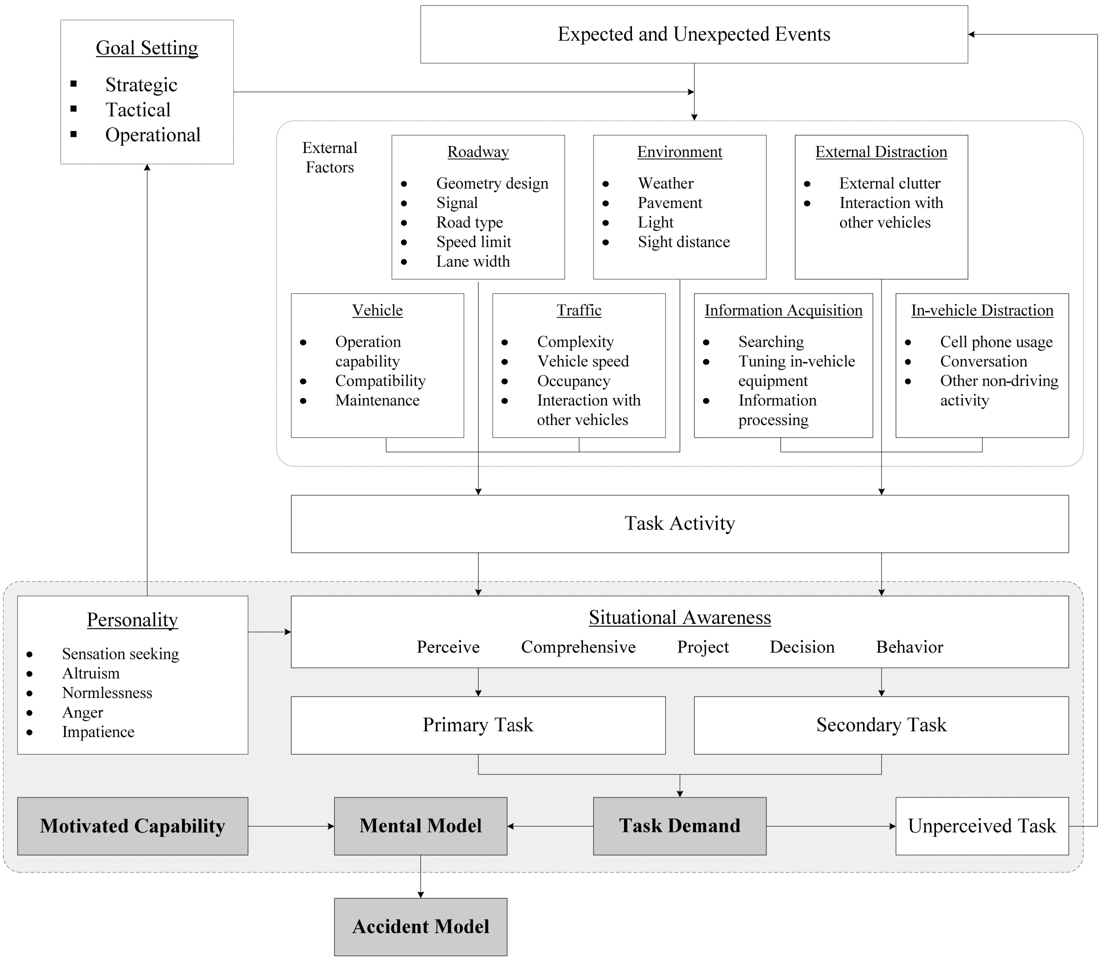


Figure 3 Research framework of driving task demand

Basically, task demand results from two task categories -- primary tasks and secondary tasks. Primary driving tasks, which are generally defined as tasks undertaken by drivers to maintain safety, can be divided into two types, controlling vehicles and preventing potential conflicts. Factors influencing driving tasks include vehicle design, traffic, road condition, distraction and external environmental factors which can influence driving task complexity and the difficulty of achieving goals. Many studies related to primary tasks have focused on analyzing accident prone scenario. For example, rear-end accidents generally occur in intersection areas since intersections require drivers to react and act in response to signal changes, particularly on the roads with more complex geometric design (Chin and Quddus, 2003; Mitra *et al.*, 2002; Wang and Abdel-Aty, 2006). In such a scenario, higher level of road design can enhance safety by making it easier for drivers to control vehicles (Horberry *et al.*, 2006b). However, better designs also encourage drivers to drive faster or take risks, thus increasing task activities (Chang and Yeh, 2007; Chin and Quddus, 2003). As a result, the driver's task demand can exceed his/her limit. Furthermore, traffic complexity is another important consideration. Recent works have found that drivers must allocate more mental resources to maintaining safety when driving under complex traffic conditions (de Waard *et al.*, 2008; Liu and Lee, 2005; Verway, 2000). Elvik (2006) also found that the more information drivers must process and the more decisions they must make, the greater the potential risk they endure while driving.

Secondary task refers to all non-driving activities, including in-vehicle distraction, external distraction and information acquisition. Undertaking secondary tasks causes distraction that shifts mental resource away from primary tasks. Among these issues, in-vehicle distraction, especially cell phone communications, has attracted heavy attention from researchers. Numerous studies have proposed that cell phone usage, or other in-vehicle instruments, increase task activities and decrease a driver's ability to react to emergencies (Caird *et al.*, 2008; Horberry *et al.*, 2006a; Liu and Lee, 2005; Nunes and Recarte, 2002; Patten *et al.*, 2004). External clutter such as advertising billboards, roadside buildings or surrounding traffic flow also were found critical to driver performance (Horberry *et al.*, 2006a). Furthermore, information provided to drivers also may cause distraction and increase task activities even when that information can help driver better pre-plan the allocation of mental resources and prevent danger arising from uncertainty.

A contributing factor analysis only deals with driver mental overload scenarios. Further exploration of these factors and associated scenarios are helpful for understanding how drivers encounter problems. Nevertheless, the most important elements in driving task activity analyses involve the behavior which drivers adopt to control their vehicles. Indeed, different behaviors might result in different task activities, thus, task demand and accident risk outcome. Young and male drivers are believed to exhibit more aggressive behaviors and violation when driving (Clarke *et al.*, 1998a; Chang and Yeh, 2007). Furthermore, male motorcyclists were found more likely to violate traffic regulations (Chang and Yeh, 2007). However, factors such as gender and age have no causal implications for driving behaviors. Instead, those observable factors reflect inherent psychological factors, such as personality traits, which can influence situational awareness or goal setting. Wong *et al.* (2009) suggested that personality traits of young motorcyclists, including sensation seeking, impatience and complaisance, can influence the occurrence of risky riding behavior. Riders who are impulsive or engage in seeking excitement have a higher acceptance of unsafe riding, and thus are exposed to more risky behaviors generating extra task activities. This phenomenon implies task activity, and thus task demand varies according to driver personality and characteristics.

3.3 Motivated Capability

Motivated capability indicates the maximum number of simultaneous task units that drivers can perform correctly during a unit of time. The law of cognitive capability proposed by Elvik (2006) suggested that capability impairment would increase accident likelihood. Figure 4 shows the framework for research on driver capabilities. As indicated, the main contributors to capability fall under physical and psychological conditions.

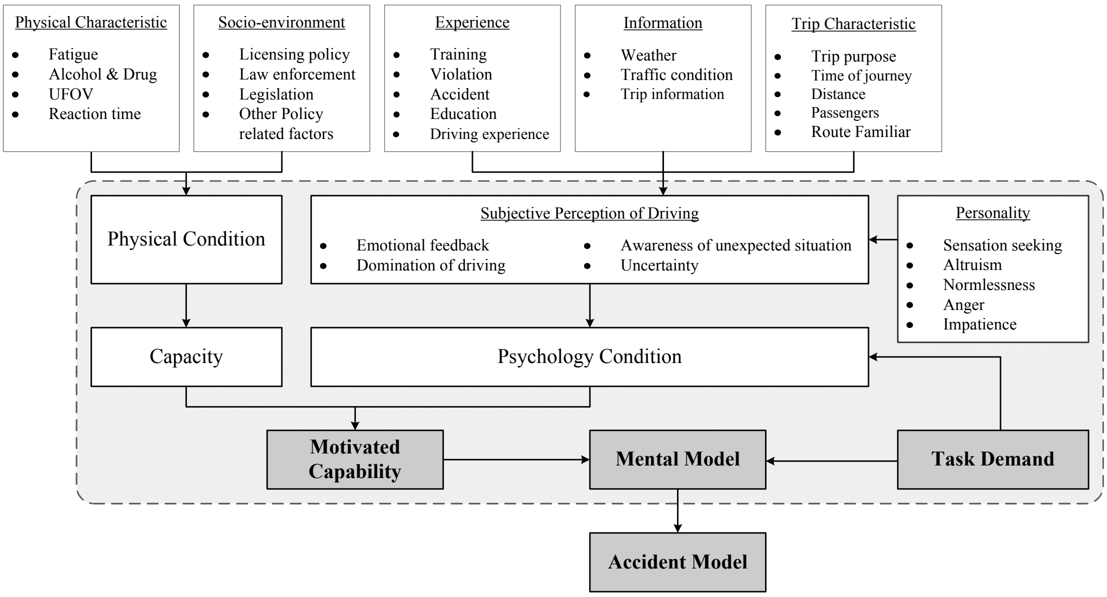


Figure 4 Framework for research on driver motivated capabilities

Drivers' physical condition forms the baseline capability, which is termed capacity. Drivers cannot increase capacity by adjusting their physical condition while driving. That is, capacity determines the mental resources limit that drivers can utilize. In discussing physical conditions, age is considered to strongly affect capacity when executing multiple and simultaneous activities (Liu and Lee, 2005; Hancock *et al.*, 2003). Owing to the degradation of physical conditions, such as consciousness, useful field of view (UFOV) or reaction time against urgent situation, senior drivers face significant changes in driving skill, reaction and, most importantly, cognitive capacity. Degradation of capacity may prevent senior drivers from identifying potential accident risk (Bayam *et al.*, 2005; Clarke *et al.*, 1999). Furthermore, use of alcohol and drugs and fatigue also can decrease a driver's capacity and thus increase the risk of getting into an accident. Lowering the driver blood alcohol limit and enforcing stricter drink-and-drive laws contribute to the reduction of accidents (Bernat *et al.*, 2004; Rios *et al.*, 2006; Ulmer *et al.*, 2000). Striker laws on blood alcohol limits and license renewal policies can help keep physically incapacitated drivers off the road.

Other important elements affecting a driver's capability are the driver's psychological condition and his/her response to task demand. A driver's psychological condition can be considered as an adjustment factor to determine how much mental resources can be utilized in driving under a given capacity. With regards to psychological conditions, a driver's subjective perceptions toward driving make critical contributions. The more self-confident and in control a driver feels, the easier it is for them to allocate mental resources and maintain their capabilities at a reasonable level. Driving under conditions where a gap exists between expectations and real traffic environment makes a driver depressed and stressed. Hill and Boyle (2007) indicated that drivers, especially female and senior drivers, who feel stressed while driving can be assumed to have reduced driving capabilities. Laws of learning and rare events proposed by Elvik (2006) also state that accident rate decreases with increasing exposure and driving experience, since positive experience accumulation and training can help drivers predict and control driving uncertainties. Furthermore, the acquisition of information about journeys including traffic conditions, weather and routing assistance can help drivers understand the situations they may encounter on their journey, and increase their confidence.

From the accident chain perspective, the greatest contributors to capability occur during the prior-to-driving stage. However, Fuller (2005) claimed that task demand, which is mostly affected by factors in the driving stage, interacts with psychological conditions and further influences level of capability. For example, a driver may pay more attention when driving on rainy days. The interaction between task demand and capability, thus, must be clarified to clearly identify the nature of mental workload.

Compared to research on task demand, few efforts had been devoted to issues involving motivated capability. Most studies have only adopted simple measures of driver capability, such as driver age. This section proposes a concept of capacity that incorporates psychological adjustment. Capacity determines the upper limit of capability. Drivers can try to optimize the utilization of driving capability by adjusting psychological related factors to improve control while driving. Individual drivers may have different physical and psychological characteristics, resulting in different interaction between capacity and capability, where capacity level is fixed and cannot be adjusted (Friswell and Williamson, 2008). Additionally, similar to task demand, motivated capability also is a dynamic system that is affected by a driver's unique characteristics in terms of information acquisition, experience and motivation along the trip. Taking age effect as an example, young drivers, in average, are in better physical conditions which give them more capacity while driving. Meanwhile, young drivers may be inexperienced and thus unable to effectively utilize their capacity. Obviously, a single simple measurement such as age or gender cannot properly explain the phenomena, and deeper discussions are necessary.

4. OPTIMUM MENTAL WORKLOAD

The previous sections discussed induction of mental workload and its influence on driving. Based on the interaction between capability and task demand, drivers suffer a certain mental workload and must react properly to prevent hazardous situations. These vehicle maneuvering manifests the explicit mental process under the influence of perceived mental workload. The risk of mental overload has been widely discussed. However, existence of mental workload does not inevitably negatively impact driving performance and safety. Instead, the concept of optimum mental workload is worthy of consideration.

Drivers attempt to maintain optimum conditions while driving, including optimum speed, stress and mental workload (Hill and Boyle, 2007; Horberry *et al.*, 2006b; Recarte and Nunes, 2002; Oron-Gilad *et al.*, 2008). When drivers become unable to optimize their mental workload, corrective action would be taken. According to the mental workload model, strategies for maintaining optimum mental workload fall into two broad categories: task demand and motivated capability adjustment.

Compensation strategies can be adopted when mental workload exceeds the optimum level. For instance, from task demand analyses, several studies have indicated that drivers try to reduce secondary tasks like ending a cell phone conversation to devote greater attention to driving (DiDomenico and Nussbaum, 2008; Törnros and Bolling, 2006). Adjusting driving behavior is another means of compensating for insufficient mental resources. For example, drivers can increase headway (de Waard *et al.*, 2007; Horberry *et al.*, 2006a) to reallocate mental resources and decrease task demand. Moreover, speed adjustment offers another means of managing mental workload. Recarte and Nunes (2002) claimed that drivers adjust speed based on their selected optimum velocity. Generally, drivers can decrease task demands by decelerating whenever their speed exceeds the optimum condition (Caird *et al.*, 2008; de Waard *et al.*, 2007; Liu and Lee, 2005). Sometimes, drivers accelerate to reduce external clutter and workload (Recarte and Nunes, 2002). In the case of psychological adjustment, drivers may concentrate more on driving and allocate more resources to the activity once they find their driving performance deteriorated (Fuller, 2005).

On the other hand, when a driver's mental workload is lower than the optimum level, he/she may suffer passive fatigue and boredom (Fuller, 2005; Gershon *et al.*, 2009; Pattyn *et al.*, 2008; Oron-Gilad *et al.*, 2008). Conditions of boredom and passive fatigue increase reaction time and possibly further increase lapses and errors. When drivers drive continuously in such low mental workload conditions, their capabilities are reduced and, moreover, they become insensitive to this degradation. Under such situation, any sudden increase in task demand can be dangerous. To prevent risks associated with low mental workload, drivers should attempt to maintain a certain level of mental workload while driving by listening to music or keeping a conversation with others in the vehicle to maintain alertness (Fuller, 2005; Oron-Gilad *et al.*, 2008).

Decision-making and acting to optimize mental workload are the key factors of road safety. However, drivers sometimes fail to accurately estimate their mental workload and underestimate potential risks. Taking cell phone usage for example, talking on a cell phone increases one's reaction time, requiring drivers to maintain a longer headway or decrease their speed to stay on the safer side. However, studies have found that drivers using hands-free cell phones do not adopt compensation strategies despite suffering the same degradation in reaction time as drivers using conventional cell phones, thus increasing accident risk (Caird *et al.*, 2008; Liu and Lee, 2005; Nunes and Recarte, 2002; Patten *et al.*, 2004; Törnros and Bolling, 2006). Therefore, it is worth considering ways to help drivers manage their mental workload by providing adequate information or assistance via ITS safety systems, such as screening out phone calls when one's mental workload is high (Nunes and Recarte, 2002; Piechulla *et al.*, 2003).

5. IMPACT OF INFORMATION ON DRIVING SAFETY

The aim of providing information to drivers is to help drivers drive more safely and easily, and most important, to help drivers optimize their mental workload. Improvements in ITS safety technology make it easier for drivers to obtain real-time traffic information. However, different information affects drivers differently. It is important to understand the characteristics of information and its impact on driving safety. Furthermore, to understand the net effect of information provided on mental workload, the contribution of information on capability and task demand must be clarified and discussed.

One of the important goals of providing information to drivers is to improve the driver's understanding of traffic situations and their influences on driving. From a user perspective, drivers note that providing more information can support decision-making and thus reduce task demand (Brookhuis and de Waard, 1999; Creaser *et al.*, 2007). Gathering real-time information, including weather, traffic flow conditions, or accident prone site, reduces drivers' uncertainty and allows them to pre-allocate their mental resources to deal with future traffic conditions. Thus, a driver's active reactions increase and passive reactions, especially those uncomfortable ones, decrease. Several studies have indicated that such active reactions to traffic conditions can effectively decrease mental workload (Fuller, 2005; Verway, 2000).

Information also is intended to help drivers maintain optimal mental workload. As mentioned, once the mental workload exceeds the critical level, drivers will select compensation strategies to alter the interaction between task demand and capability. However, drivers sometimes misestimate potential risks in certain conditions and make wrong decisions . As indicated, drivers may underestimate the potential risk and end up not reducing their speed or increasing headway when using hands-free phones (Caird *et al.*, 2008; Liu and Lee, 2005; Nunes and Recarte, 2002; Patten *et al.*, 2004; Törnros and Bolling, 2006). A mechanism for in-vehicle cell phone management has been proposed to screen out incoming calls when one's mental workload exceeds a certain level (Nunes and Recarte, 2002; Piechulla *et al.*, 2003). On the other hand, if the mental workload is far below the optimum level and there is a risk of passive fatigue, external stimuli such as music or radio should be provided to increase task demands and hence driver alertness (Fuller, 2005; Pattyn *et al.*, 2008; Oron-Gilad *et al.*, 2008).

While information is generally beneficial, improper use of it can gain negative effects. Only providing the proper information to right driver at the proper time and place can exert positive effects and reduce accident risk (Wong and Chung, 2007a). Complex laws proposed by Elvik (2006) state that accident risks are increased with the information drivers must attend to during a given unit of time. Moreover, side effects of information should also be considered. Drivers influenced by multiple sources of information likely are to be distracted and miss critical information. Therefore, information overload will not help drivers and may even cause serious problems by distracting them. Figure 5 illustrates the impact of information provision on each element of the mental model. The dashed box represents the contribution of information during each stage. To prevent negative effects resulting from interference of ITS systems or other sources, analyses of information optimization and allocation is crucial for future ITS development and application (Verway, 2000).

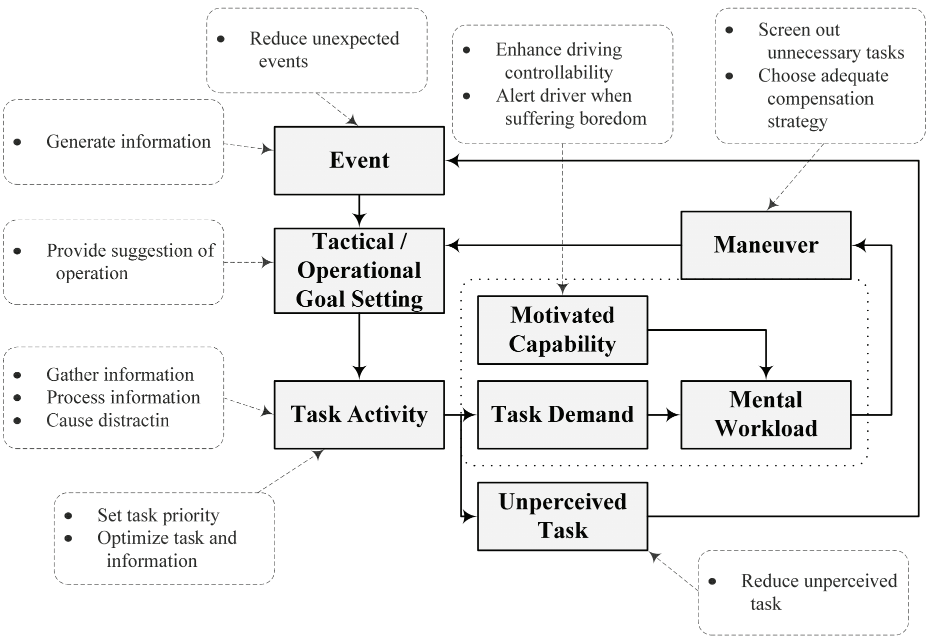


Figure 5 Impact of information provision

As shown in Figure 5, information can contribute to mental workload in each stage of driving and can simultaneously exert positive and negative effects. Furthermore, differences in the reactions of individual drivers to external stimulation, information customization and personalization must be considered. The success in doing so depends on a workable mental workload model. Individual capability and reaction to task demand changes in response to certain information under specific conditions should be evaluated. Consequently, via the proposed research framework, information prioritization hopefully can be conducted and effectively provided for each scenario, thus helping drivers select the most appropriate strategy.

6. ISSUE DISCUSSION

Analyzing accidents from the perspective of the individual mental model can help clarify the nature of accident causation and the interactions involved in the cognition associated with driving. This study presents a research framework for a mental model that incorporates task demand and capability to measure mental workload. However, several issues are worthy of consideration.

The first issue is overall mental model formulation. Most studies have focused on the interaction between task demand and mental workload. By giving a series of primary tasks and secondary tasks to drivers, researchers are able to observe changes in overall mental workload towards task activities (Caird *et al.*, 2008; de Waard *et al.*, 2008; Horberry *et al.*, 2006a; 2006b; Liu and Lee, 2005; Verway, 2000). However, the level of mental workload is based on the difference between task demand and driver capability (Fuller, 2005). Neglecting the contribution of capability might bias the interpretation of mental workload. Several studies have discussed the effect of gender and age on the basis that they possibly reflect a driver's capability (Caird *et al.*, 2008; Fuller, 2005; Hancock *et al.*, 2003; Liu and Lee, 2005; Makishita and Matsunaga, 2008), but few have discussed the capability motivated in different situations and personality characteristics.

The second one is measurement. To clarify the interaction between capability and task demand, measuring and quantifying each element is important. However, no index of task demand equivalent can be adopted to evaluate task demand intensity. The same difficulty occurs when measuring driver capabilities or determining the threshold of optimum workload. Moreover, capability is dynamic and varies with changes in driving task activities. Though "capability" is used here, in reality drivers may have multiple capabilities, each of which can be influenced by different task demands. Identifying and clarifying task demand and capability is a major challenge and also a critical step in constructing the mental workload model.

The subsequent difficulty in developing a mental model lies in measuring mental workload. Since the workload is difficult to directly observe and quantify, latent variables were used as measurements. The most commonly adopted approaches can be broadly divided into three categories: subjective self-report questionnaire (Hart and Staveland, 1988; Horberry *et al.*, 2006a), physiology measurement (de Waard *et al.*, 2008; Hill and Boyle, 2007) and driving performance (Törnros *et al.*, 2006; Vashitz *et al.*, 2008). However, sensitivity of each measurement may vary with the situations. Horberry *et al.* (2006a) found that performance difference is not significant in low mental workload conditions despite subjective questionnaires showing that drivers had been influenced by tasks. Considering differences in measurement characteristics, an integrated indicator incorporating each methodology should be considered (Jung and Jung, 2001; Miyake, 2001).

The fourth is model structure. The inverse proportion relation between workload margin and mental workload indicates that a two-stage model structure deserves considerations. When the workload margin is comparatively high, driving task turns out more like an automated behavior and drivers do not have to allocate too many resources on driving and have a larger buffer to perform other secondary tasks. Previous studies also revealed that differences in secondary tasks or task complexity do not make any difference in mental workload under simple scenarios (Horberry *et al.*, 2006a; Liu and Lee, 2005; Matthews *et al.*, 2003). Once the task demand exceeds the threshold, mental workload begins to increase with increasing task demand.

Finally, according to Figure 3 and Figure 4, the mental workload model is designed to identify the causative links between disaggregate information and accident occurrence. However, mental workload overload is not necessarily linked to accidents. Instead, the issue of mental workload should be considered a critical element in the accident chain. Accident occurrence relies on interaction among drivers, the environment and other road users. The relationship between mental workload model and accident model requires further exploration.

7. CONCLUDING REMARKS

Mental model is a critical element for clarifying the nature of traffic accidents. Previous studies mostly focused on the interaction between contributing factors and the occurrence of accidents. However, accident prone scenario can only explain what accidents occur and the mechanisms through which they occur, but not why they occur. Since drivers perceive external stimuli and control vehicles, understanding the characteristics of driver mental process is crucial for clarifying the question of “why drivers fail to maintain safety under certain circumstances.” To fill the gap, developing a research framework is an important step towards the development of a workable mental model to gain insight of accident causality.

Review of the related literature reveals several difficulties in assessing mental workload. First, task demand and motivated capability, which can be seen as the demand and supply of mental resource, represent the two major components of the mental workload model. Focusing on either task or capability only cannot reveal the nature of driving mental process. Second, considering the complexity of real driving environments, drivers perceive multiple events simultaneously while driving. Single factors such as driving speed, headway or distraction level do not reflect the true situation. Meanwhile, task demand and motivated capability are considered a dynamic system which varies according to driving conditions. Without a further understanding of state transit that may affect mental workload, the nature of driving mental process can not be clarified.

Issues of mental workload models still require further discussion and study. Identifying the cognitive interaction of drivers while driving is a necessity for understanding accident causality. Therefore, this study proposed a research framework that incorporates task demand and capability to identify mental workload. Furthermore, drivers have increasing access to information. The provision of large quantities of poor quality information, however, can create serious problems of information overload and distraction. Applying the mental workload model in accident chain analyses enables the discussion of the net effect of information on mental workload. Optimized information hopefully can be defined and provided to drivers in different scenarios without causing additional risk of accidents.

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VEHICLE DRIVER'S DOMAIN FOR DRIVING ATTENTION ALLOCATION ANALYSES

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ABSTRACT

The increasing number of roadway accidents has led researchers to focus on accident-prone scenarios to get a clearer picture of the accident occurrences through accident chain. However, such scenarios explain the conditions and mechanism of a collision rather than its true cause. To fill the gap between occurrence and causality, analyzing individual drivers' attention allocation processes is vital for clarifying the nature of accidents. Noting that driving is a continuous process of information collection, drivers need to allocate attention to different objects to perceive useful information. Attention misallocation can be seen as the missing link between an accident-prone scenario and the occurrence of an accident. Modeling drivers' attention allocation in different conditions is a major step in identifying the external information drivers perceive and react to. The purpose of this research is to analyze the process of driving attention allocation through the divided attention model. Moreover, the concept of the vehicle driver's domain is proposed. By identifying the risk level of threats to safety in each type of vehicle driver's domain, the central allocation policy of attention resources can be identified.

INTRODUCTION

To enhance the understanding of accidents, researchers have worked on mining aggregated accident data to extract accident patterns. Numerous contributing factors, including the demographic characteristics of the driver (Chang and Yeh, 2007; Clarke *et al.*, 1998), vehicle (Albertsson, 2005; Chang and Yeh, 2006), road geometry (Chin and Quddus, 2003; Mitra *et al.*, 2002; Wang and Abdel-Aty, 2006), and environmental conditions (Eisenberg, 2004; Keay and Simmonds, 2006), have been found critical to roadway safety. Despite the significant effect of single factors, recent research has further claimed that accidents should be analyzed from a chain perspective in which remote factors also may contribute to their occurrence (Verschuur and Hurts, 2008; Wong and Chung, 2007a; 2007b; Wong *et al.*, 2010).

Exploring accident chains provides valuable clues that indicate accident-prone scenarios in which drivers usually have a higher risk of being involved in a dangerous situation. Such accident-prone scenarios explain mostly the conditions in which drivers face higher risks of being involved in an accident, and possibly the mechanism through which such accidents occur. However, an unanswered question remains, namely, why accidents occur under specific conditions. In fact, different drivers react differently in identical situations. While most drivers can still drive safely in a high accident risk scenario, but some fail to maintain safety, resulting in dangerous situations. The question thus arises: How do different reactions to identical conditions result in various outcomes. Answers to the question rely on the understanding of drivers – the decision-maker of a running vehicle.

Research conducted in different countries has suggested that human factors are the most important contributor to accident occurrence (Chen *et al.*, 2005; Horberry *et al.*, 2006a; Dahlen *et al.*, 2005; FMCSA, 2009; Liu and Lee, 2005; Makishita and Matsunaga, 2008; Reed-Jones *et al.*, 2008; Ulleberg and Rundmo, 2003). In Taiwan, for example, 85 percent of fatal accidents in 2008 resulted from human-related factors (such as traffic violations and aggressive behavior). Among those factors, "failed to note road conditions," which can be considered as attention misallocation and failure of risk awareness, accounted for 22 percent of human-related fatal roadway accidents (MOTC, 2009). Research conducted in the United States also found that distraction and inattention of a driver are the most important human-related causes in accidents (FMCSA, 2009).

In fact, the frequent occurrence of failing to note road conditions represents distraction and misallocation of attention. Attention misallocation can be seen as the missing link between accident-prone scenarios and accident occurrence within the concept of an accident chain. Driving in an accident-prone scenario may not necessarily result in an accident, provided that the driver's attention is well allocated. Attention misallocation in such scenarios will sharply increase the likelihood of an accident.

Noting that driving is a continuous process of information collection, comprehension, decision-making, and execution, collecting complete information is the key factor in safe driving. Driving-related information includes speed, the existence and attributes of other vehicles, roadway geometry, route information, signs, and traffic signals. Acquisition of incomplete or useless information will lead to insufficient comprehension of the current driving environment, misjudgment, and possibly accidents. To drive safely, drivers are forced to pay attention to multiple information sources in order to make correct driving decisions. Therefore, attention allocation issues arise.

Attention is consciousness and perception with focalization and concentration toward stimuli (Zomeren and Brouwer, 1994). The attention model proposed by Kahnement (1973) claimed that one's mental resources are limited. Therefore, attention must be divided and given to different activities. The concept of divided attention is based on the idea of mental effort, which describes how demanding an activity might be. From a driver's point of view, (s)he has a central processor of attention allocation policy to allocate mental resources and attention under the limit of attention capacity. Problems of divided attention may degrade the ability to detect potential threats while driving (Creaser *et al.*, 2007; de Waard *et al.*, 2009; Laberge *et al.*, 2006; Marmeleira *et al.*, 2009).

Driving distractions can be defined as attention misallocation and the shifting of attention from driving tasks to other stimuli activated by objects or events (FMCSA, 2009). Shifting attention away from road conditions and driving tasks may increase the time required to perceive and react to external stimuli, and thus increase accident risks (Neyens and Boyle, 2007). In-vehicle distraction caused by undertaking secondary tasks, especially cell phone communication, has attracted much attention from researchers. Numerous studies have proposed that using in-vehicle instruments, such as cell phones, navigation systems, or in-vehicle information systems, increases the amount of task activity and decreases drivers' ability to react to emergencies (Caird *et al.*, 2008; Horberry *et al.*, 2006a; Liu and Lee, 2005; Nunes and Recarte, 2002; Patten *et al.*, 2004). Furthermore, external clutter such as advertising billboards, roadside buildings, or traffic flow were also found to be critical to driving performance (Horberry *et al.*, 2006a). In addition to the degradation of risk perception, driving distractions can also be seen as misallocation of mental resources. Maintaining attentive focus on road conditions and vehicle operation is the primary task of driving. Undertaking secondary tasks can cause distraction and increase the mental workload.

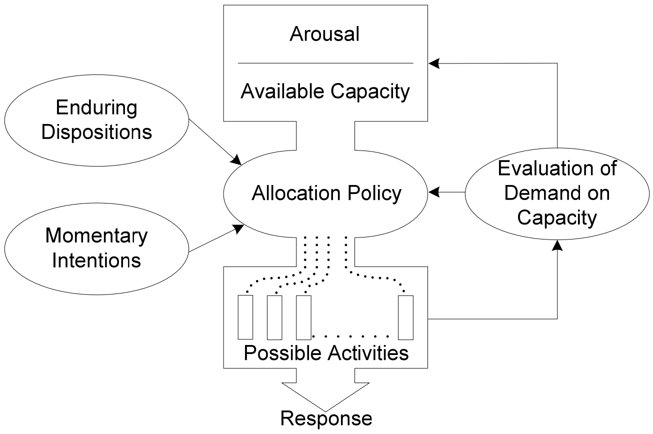
Furthermore, driving information provided to drivers may also cause distraction and increase mental tasks while driving. Providing driving information is intended to help driver better plan the allocation of mental resources and prevent dangers arising from uncertainty. From a user perspective, drivers note that providing more information can support decision-making and thus reduce task demands (Brookhuis and de Waard, 1999; Creaser *et al.*, 2007). Gathering real-time information, such as that regarding weather, traffic flow conditions, or accident-prone sites, reduces drivers' uncertainty and allows them to pre-allocate their mental resources to deal with future traffic conditions (Fuller, 2005; Vashitz *et al.*, 2008; Verway, 2000). However, its improper use of information can yield negative effects. Complex laws proposed by Elvik (2006) state that accident risks increase with the amount of information drivers must attend to during a given period of time. Providing only the proper information to the right driver at the appropriate time and place can exert positive effects and reduce accident risk (Vashitz *et al.*, 2008; Wong and Chung, 2007a). The side effects of information should also be considered. Drivers influenced by multiple sources of information are likely to be distracted and miss critical information (Liang *et al.*, 2007; Vashitz *et al.*, 2008).

As stated, attention misallocation can be seen as the missing link between accident-prone scenarios and accident occurrence within the concept of accident chains. To model drivers' attention allocation and distraction, the concept of the vehicle driver's domain is proposed in this research. Modeling attention allocation and subsequent behavior through the vehicle driver's domain is a major step in identifying the external information drivers perceive and react to. As a consequence, the effect of information on perception, driver behavior, and mental workload can be further clarified. Moreover, the connection between accident risks attributed to distraction and drivers' mental processes could be established.

An attention allocation model and its application to driving are introduced in section 2. In section 3, the concept of the vehicle driver's domain is proposed. Section 4 then proposes a model framework of driving attention allocation. Finally, discussion and concluding remarks are presented.

ELEMENTS IN ATTENTION ALLOCATION

The divided attention model (Kahnement, 1973) stats that several activities can be focused on and carried out at the same time, provided that their total effort is below the limit of available capacity. Four attributes of attention are mentioned. First, attention capacity is limited and varies from time to time. Available mental resource vary with the arousal level based on the physiology characteristics.. Second, the amount of attention or mental resources allocated is based on the demand level of current activities. The more demanding an activity is, the more attention would be allocated to it. Third, attention is divisible. Fourth, attention is selective and controllable. A central policy exists for allocating attention to selected objects or activities. The framework of the divided attention model is illustrated in Figure 1.



Source: Kahnement (1973)

***Figure 1** – Model of divided attention*

Four major elements are used to determine attention allocation policy in the model of divided attention: arousal, enduring dispositions, momentary intentions, and evaluation of demand on capacity. Arousal refers to factors such as physical condition, fatigue, or nervous tension that may activate the maximum attention capacity. An adequate level of arousal must be maintained. Under-arousal causes low attention capacity, whereas over-arousal impairs the ability to discriminate relevant objects from irrelevant objects. Enduring dispositions and momentary intentions reflect the characteristics of the external environment and behavioral intentions. Enduring dispositions represent state changes in the environment, such as deceleration of the vehicle ahead, and reflect involuntary attention. Momentary intentions, in contrast, represent the intended attention allocation at that instant, such as searching for information using an in-vehicle information system. Finally, the feed back of attention allocation would continue to evaluate and adjust the arousal level and revise the allocation policy to fit the current situation.

To obtain complete information for driving, drivers need to allocate attention on multiple objects not only on the road but also off-the road. For example, if a driver focuses only on traffic conditions in an adjacent lane and is not aware that the vehicle ahead is decelerating while changing lanes, an unexpected headway decrease may shorten the available time for the driver to react properly and increase the risk of collision with the vehicle ahead. This accident chain may describe a rear-end collision while changing lanes. However, the key points of accident risk in such a situation are the failure of divided attention and the driver's attention misallocation. Thus, the concept of divided attention is useful for analyzing driving safety.

Previous research has indicated that the capacity for divided attention is critical for situational awareness, especially for senior drivers (Creaser *et al.*, 2007; de Waard *et al.*, 2009;

Laberge *et al.*, 2006; Marmeleira *et al.*, 2009). Experiments on the influence of driving distraction on safety have also been conducted (Caird *et al.*, 2008; Horberry *et al.*, 2006a; Liu and Lee, 2005; Nunes and Recarte, 2002; Patten *et al.*, 2004). However, little numerical evidence has been provided for the mechanism that determines how drivers shift attention among different areas, objects on the road, and information sources. To better comprehend how drivers allocate attention to multiple threats and information sources, the model of divided attention is adopted to dissect the process of driving and information perception. Meanwhile, the vehicle driver's domain is proposed as a tool for representing the complicated interaction of objects in a real driving environment.

VEHICLE DRIVER'S DOMAIN

The vehicle driver's domain is proposed to simplify the complex interaction of multiple threats to safety by setting three virtual boundaries, which form three domains, around subject vehicles. It helps to identify the location and characteristics of threats to safety. Threats inside different domains under different driving conditions reflect different meanings to drivers and draw different levels of attention. In this section, the role of the vehicle domain in mental processes and attention allocation in driving is introduced. Then, the characteristics and measurement of each domain are explained.

Definition of Vehicle Driver's Domain

The vehicle driver's domain is the area within a specific distance around the subject vehicle. It is a driver's conceptual area in which external objects may appear to interact with the subject vehicle and degrade driving safety. Such threats to safety include other vehicles, fixed objects, curbs, and pedestrians. The concept of the vehicle driver's domain is important for situational awareness, risk perception, and decision making regarding threats to safety while driving. This distinct area contains the information that drivers are able to perceive, collect, and process. To prevent collisions, drivers must allocate attention inside the vehicle driver's domain and seek complete information. As shown as Figure 2, drivers generally set three boundaries, forming three kinds of vehicle driver's domains: the distant area in which drivers can perceive external stimuli, the area in which the driver is preparing to make a maneuver, and the relatively close area where driver must secure to prevent traffic conflict within limited time. These domains are named the perception domain, reaction domain, and critical domain, respectively. The content of these three domains can attract the driver's attention and effect traffic safety differently.

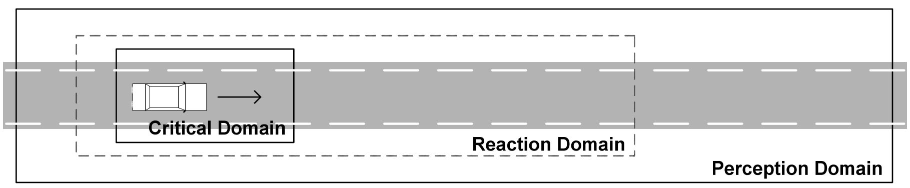


Figure 2 *- Concept of vehicle driver's domain*

A vehicle can be seen as a system containing subsystems with different functions to ensure safe driving. Each subsystem will vary the conditions of the three vehicle driver's domains. The person behind the wheel is one of the most important components within the vehicle system. Objects located in different domains should activate different reactions and behavior from the driver owing to their varying risk levels. Figure 3 shows the mental process of driving and the role of the vehicle driver's domain in this process.

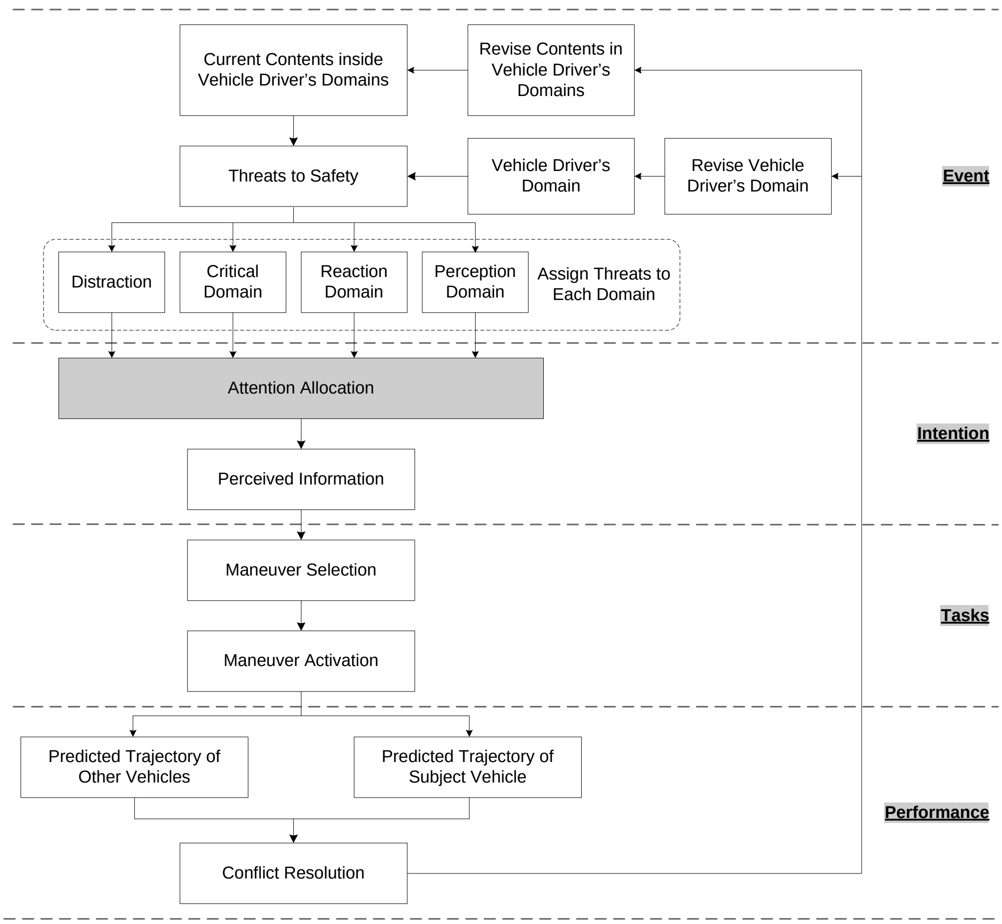


Figure 3 – *Driving mental process and vehicle driver's domain*

Driving can be divided into four mental stages: event occurrence, intention, tasks, and performance. Drivers first perceive objects, which can be seen as the current content inside the vehicle driver's domain. Each object perceived is evaluated as a threat to safety on which attention should be focused. These threats are immediately mapped onto the three conceptual vehicle driver's domains. In facing those threats, drivers, if not distracted, must allocate attention to collect information necessary for driving safely.

The second stage is attention allocation to threats to safety. As described in the model of divided attention (Kahnement, 1973), drivers can focus on multiple threats on the road and allocate different levels of attention to different objects. The more demanding the objects are, the more attention they would be allocated. In this research, drivers are assumed to allocate more attention to objects or areas with a high level of accident risk to minimize the expected negative impact on safety. However, not all objects inside the vehicle driver's domains will be observed and considered as threats to safety. Some may be ignored due to drivers' inattention. Some may be attended to and observed but seen as potential threats that pose no immediate danger of collision. On the other hand, non-driving tasks may cause distraction, shifting attention away from primary driving tasks.

Based on observation of threats to safety in different domains in a real-time driving environment and the driver's perception of their importance, maneuvers are selected and executed. After undertaking the selected maneuvers, a new driving state, including speed, location, and trajectory, is realized. Therefore, the vehicle driver's domain may need to be revised. Meanwhile, threats on the road are also changing continuously. The current contents of the vehicle driver's domain should be revised to iterate the attention allocation process.

Threats in different vehicle driver's domains require different tasks to resolve them. To model driving behavior based on attention allocation, it is important to define and explore the characteristics of each vehicle driver's domain. Then, the threats to safety that drivers really see and care about can be further clarified.

Measurement of Vehicle Driver's Domains

The concept of the vehicle driver's domain is of major importance in situational awareness, decision making, and preventing collision. The size and shape of each domain are important for defining their distinctive areas. In the following sections, the definition and measurement of each domain are explained. Also, threats to safety that may be of concerns to drivers are identified. Finally, based on threats to safety in each domain, the process of attention allocation within the domains is introduced.

Perception Domain

The perception domain reflects the respectively far area in which a driver has plenty of time to perceive stimuli from the external environment. Inside this area, moving objects are identified and evaluated as potential threats to safety. In other words, this domain contains all the information available from all the objects on the road to which the driver can attend. Once a driver perceives the existence of certain objects inside the perception domain, mental resources are consumed to evaluate the risk level of the threat to driving safety. After perceiving potential threats, drivers continue tracking the movement and predicting possible interactions between threats and the subject vehicle. However, no immediate technical tasks, such as changing speed or direction, are made when objects are located in perception domain but outside the reaction domain. Most tasks undertaken with respect to threats inside the perception domain are non-technical, reflecting the mental activities of perceiving, comprehending, and projecting information. The important factors in the perception domain are shown in Figure 4.

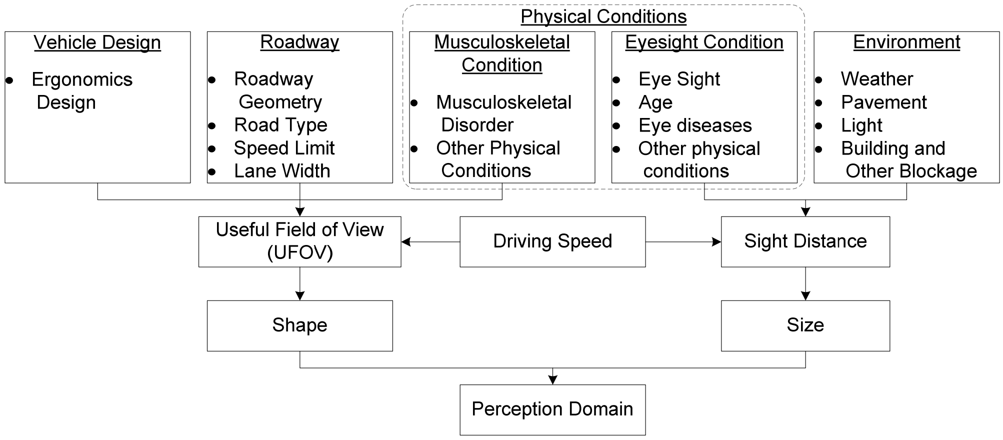


Figure 4 ***–****Important factors of perception domain*

The farthest distance of the perception boundary, which defines the size of the perception domain, refers to the sight distance under certain speed and environmental conditions. The maximum sight distance depends on the driver's visual capability, which is related mostly to his or her physical capabilities. For example, senior drivers have been indicated as having serious degradation of eyesight (Bayam *et al.*, 2005; Clarke *et al.*, 1999). The external driving environment also affects the available sight distance. For example, the sight distance while driving on a rainy night without streetlight is much shorter than that on a sunny day. Moreover, blockages caused by buildings and roadway geometry block driver's eyesight and shorten the sight distance.

The shape of the perception domain represents the directions in which a driver can see and allocate attention. It can be defined by the extent of the vision field, which is influenced by the driver's physical condition and the vehicle's ergonomics. Peripheral vision is one characteristic of the useful field of view (UFOV) that affects the visual field span. Although peripheral vision can extend 90 degrees to the right and left sides, only the center of the visual field is clear enough to capture stationary objects on the road (Roess *et al.*, 2004). Moreover, a driver's peripheral vision reaches a limitation as the speed of the vehicle increases. Also, a driver's musculoskeletal condition restricts the visual field's span. Drivers with muscle disorders and other physical disabilities may find it difficult in turning the head to increase peripheral vision. Vehicle ergonomics design is another critical factor that restricts the visual field. Rear-view mirrors allow drivers to detect and observe traffic conditions behind the vehicle, where drivers cannot observe and pay attention directly. However, blind spots may still exist and may pose risks to driving safety.

Critical Domain

The critical domain represents a safety boundary; drivers must secure this area and prevent objects from entering it. Objects inside the critical domain are seen as the occurrence of accidents. Although drivers can still allocate attention to threats inside the critical domain, yet, accidents are not preventable. If the threats to safety are close to the critical boundary or inside the critical domain, immediate technical tasks must be performed. The important factors in the critical domain are shown in Figure 5.

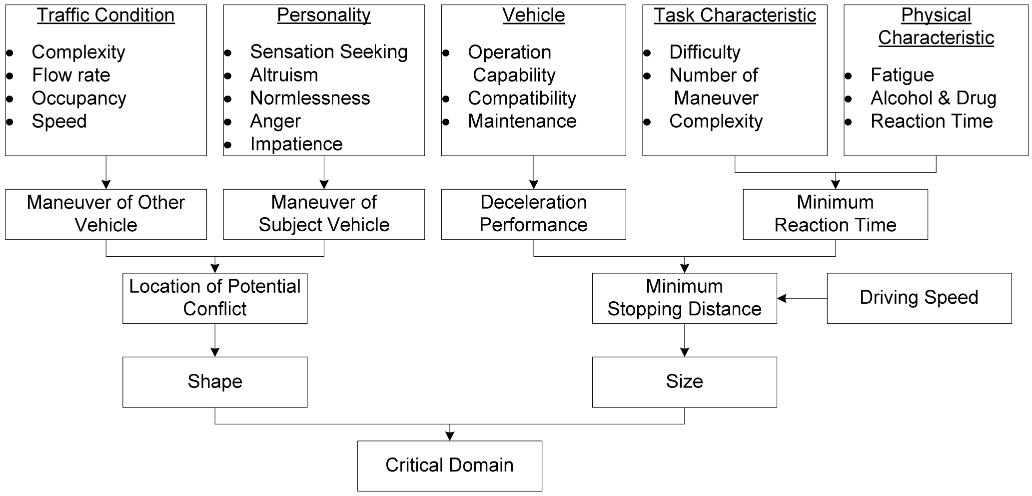


Figure 5 –*Important factors of critical domain*

Reaction capability is the key factor determining the size of the critical domain. Factors contributing to reaction capability include the driver's reaction time and the vehicle's deceleration performance. Those two factors determine the minimum stopping distance in response to external stimuli. When the distance between the subject vehicle and a threatening object is shorter than the stopping distance, an accident cannot be prevented. In regarding to the size of a critical domain, the driver's reaction time is rather important. Fatigue and alcohol or drug usage may degrade one's reaction capability by increasing the reaction time. Regardless of a driver's physical characteristics, task difficulty may influence the reaction time as well. Characteristics of technical tasks, such as complexity or difficulty in performing them, are reflected in the reaction capability and the critical domain. Drivers may take more time to notice an emergency situation, make decisions, and take action if they must perform more maneuvers.

The shape of the critical domain is determined by event characteristics and the maneuvers chosen based on the driver's intentions. It indicates the direction and location at which threats may appear and lessen driving safety. In other words, the shape of the critical domain indicates the area drivers should focus on to prevent collisions. It depends on the predicted potential conflicts of vehicle trajectories. Each event occurrence and task creates different potential conflicts in different locations on the road, making differently shaped critical domains. Figure 6, for example, shows three different maneuvers: driving in the current lane, changing lanes, and turning right. Each creates a unique potential conflict and critical domain. When driving without changing lanes, as in Figure 6 (A), the critical domain contains only the area in front of the vehicle to prevent collisions with the vehicle ahead, and limited space in adjacent lanes to prevent other vehicles from entering the current trajectory. However, when drivers decide to change lanes, as in Figure 6 (B), the critical domain extends to the adjacent lane to prevent collision with vehicles ahead and behind. Thus, attention should still be allocated to the current driving lane to maintain a safety gap with the vehicle ahead while awaiting a time to change lanes. In the case of a right turn when approaching an intersection, the critical domain may extend in the direction perpendicular to the direction of travel. Drivers have to secure the area and prevent pedestrians and other moving objects from entering the critical domain.

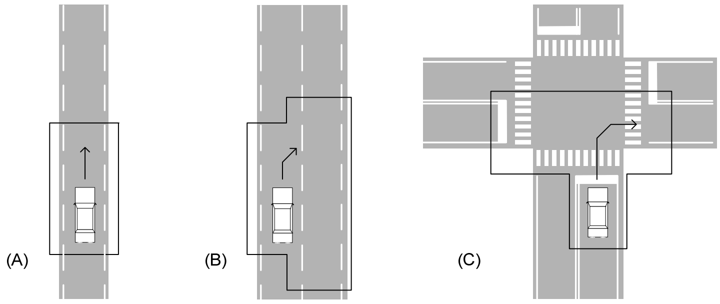


Figure 6 – *Critical domain under different maneuvers*

Reaction Domain

The reaction domain is the area in which potential threats are determined to be threats to safety that drivers must pay close attention to and in which drivers must react to any stimuli appearing. Typically, the reaction domain is located between the perception and critical domains. When a potential safety threats crosses the boundary of the reaction domain (the reaction boundary), drivers determine that those objects are threats to safety and allocate more attention to them. Drivers may make certain maneuvers to prevent collision. Both technical and non-technical tasks are necessary when handling threats inside the reaction domain. The important factors in the reaction domain are shown in Figure 7.

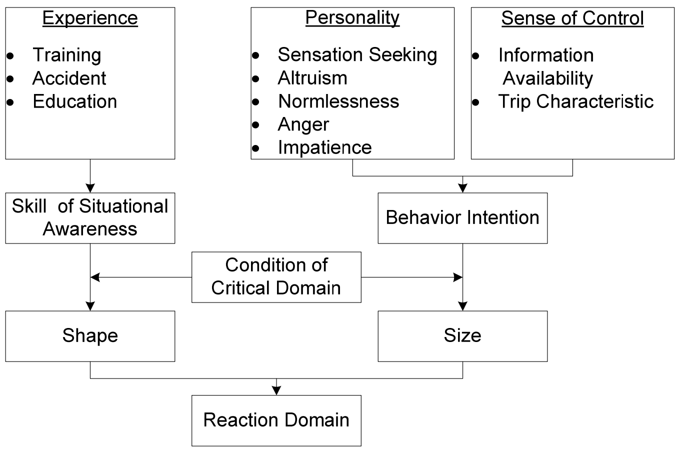


Figure 7 – *Important Factors of Reaction Domain*

The reaction domain is mostly affected by the individual driver's characteristics. The size of the reaction domain depends on where the driver locates the reaction boundary for activating reactions to safety threats. The selection of the reaction boundary depends on the driver's skill and situational awareness. Laws of learning and rare events proposed by Elvik (2006) stated that the accident rate decreases with increasing exposure and driving experience, since positive experience accumulation and training can help drivers predict and control uncertainties. In other words, experienced drivers likely are able to make a better decision when facing safety threats. Additionally, previous research has found that experience, personality, attitude, and other psychological factors play a role in one's driving behavior (Chang and Yeh, 2007; Taubman-Ben-Ari *et al.*, 2004; Ulleberg and Rundmo, 2003; Wong *et* *al.*, 2009a; 2010). With different behavioral intentions, drivers may make different decisions and react differently in the reaction domain. This suggests that individual drivers' characteristics should be considered.

The driver's sense of control also contributes to the selection of reaction boundary. For instance, having road information, such as traffic conditions, weather information, and routing assistance, at hand can help drivers understand the situations they may encounter and increase their confidence. The more self-confident and in control drivers feel, the easier it is for them to allocate attention and maintain their driving performance at a reasonable level. On the contrary, driving under conditions where a gap exists between expectations and the real traffic environment stresses and discourages a driver. Research has stated that stress can influence a driver's capability and cause attention misallocation cause attention misallocation (Hill and Boyle, 2007).

The shape of the reaction domain is closely related to the conditions of the critical domain; it is similar to the critical domain but different in size. Like the size of the reaction domain, its shape relies on the driver's skill and situational awareness. It reflects a driver's behavioral intention and determines a driver's attention allocation policy regarding objects and quality of decision making.

DRIVING ATTENTION ALLOCATION

This section discusses the threats inside each domain and the interaction between threats and the subject vehicle. The driving attention allocation process can be divided into two parts. First, threats to safety in each domain are identified. The risk level of the threats can be seen as a combined index of enduring dispositions and momentary intention while driving. The risk level also reflects the demand of each object for attention allocation. Second, the attention allocation policy, which is represented as the probability of a specific domain being focused on by drivers, is determined based on the risk level of threats to safety in different domains.

Threats to Safety

Threats in this study can be defined as possible dangers that may harm driving safety. To identify the attention allocation process while driving, it is important to determine the kind of threat that may influence safety and to what extent. The risk level of threats to safety is adopted to represent the criticalness of threats is in different maneuvers and driving environments.

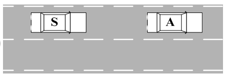
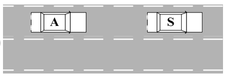
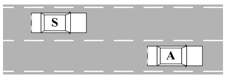
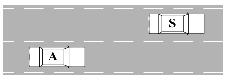
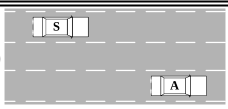
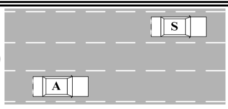
Risk is evaluated on the basis of three factors. The first is the distance between a subject vehicle and a threat. In this research, the location of a specific threat can be represented by the domain to which it belongs. The second factor is the traffic flow in which drivers are driving. When facing different traffic flow conditions, drivers may allocate attention to different domains. Three levels of traffic are considered: free flow, synchronized flow, and congested flow. The third factor is the interaction between the subject vehicle and the threat. It relies on the relative locations of the vehicle and the threat and the maneuvers adopted by the vehicle's driver. Provided that the maneuvers decrease the headway, they can be considered as raising the risk of conflict, requiring more attention from drivers. Characterizing threats using these three factors can help identify the interactions of the subject vehicle and other objects on the road. Furthermore, it can help describe the actual driving environment and capture critical attributes that can influence driving safety.

The risk level of threats to safety caused by interactions between a subject vehicle and other vehicles under different traffic flow conditions are summarized in Tables 1 to 3. Assuming that only interactions within driving lanes are discussed, four maneuvers (maintaining speed, accelerating, decelerating, and changing lanes) may be undertaken by the subject vehicle (Vehicle S) and the threat (Vehicle A). Seven scenarios representing the relative locations of two objects and reflecting different driving maneuvers and types of potential conflicts are illustrated.

The first and second scenarios indicate the potential threat of rear-end conflicts with vehicles in the same lane. In the first scenario, Vehicle S follows other vehicles, and in the second, the Vehicle S drives in front of other vehicles. If drivers stay on the same lane without changes, they must pay attention to threats located on the lane they are on to prevent rear-end accidents. However, drivers should pay attention to vehicles running in the adjacent lane that may pose a risk of side impact if they change lanes. The third and fourth scenarios represent the potential threat of side impact from the front and the rear in the adjacent lane. The fifth and sixth scenarios denote a threat located in a second adjacent lane. If a driver intends to change lanes, vehicles in the adjacent lane (the third and fourth scenarios) and the second adjacent lane (the fifth and sixth scenarios) are considered as safety threats. The seventh scenario refers to a fixed object on the road.

Table 1 summarizes the risk level of threats to safety when driving in the free flow condition. In this condition, by definition, drivers can adjust speed without being influenced by other vehicles. In other words, no other vehicle appears inside the reaction and critical domains, in which the driver would initiate reaction against external stimuli. The closest vehicle that could affect driving safety in free flow traffic is located in the perception domain. Thus, only threats in front of the subject vehicle would affect driving safety, including the vehicles ahead in the same lane (as in the first scenario) and vehicles in the adjacent lane that may cause risk if they change lanes (as in the third and fifth scenarios). The risk level is comparatively low, since any threats are still far away and outside the reaction domain. However, if the headway is decreasing, the threats to safety could enter the reaction domain; the risk level would increase, and the threat will draw more of the driver’s attention. Meanwhile, due to the narrow span of a driver’s vision when driving in free flow traffic condition, drivers would not only attend to the vehicle ahead but also those behind and on adjacent lane Compared to other vehicles on the roads, the risk level of fixed roadside objects is more significant for safe driving. Drivers would perceive more risk in roadside object located in the reaction and critical domains, especially roadside curbs on curving lanes, which may necessitate a technical task of wheel-turning.

***Table 1** – Risk level of threats to safety in free flow*

Maneuver Undertaken by Vehicle A (rows) / Maneuver Undertaken by Subject Vehicle (columns)		Subject Vehicle Driving in Free Flow											
		Perception Domain				Reaction Domain				Critical Domain			
Related Location of Threats	Maneuver	Maintain Speed	Accelerate	Decelerate	Change Lane	Maintain Speed	Accelerate	Decelerate	Change Lane	Maintain Speed	Accelerate	Decelerate	Change Lane
(1) 	Maintain Speed	L	L	-	-	Not Applicable				Not Applicable			
	Accelerate	-	L	-	-								
	Decelerate	M	M	-	L								
	Change Lane	-	-	-	L								
(2) 	Maintain Speed	-	-	-	-								
	Accelerate	-	-	L	-								
	Decelerate	-	-	-	-								
	Change Lane	-	-	-	-								
(3) 	Maintain Speed	-	L	-	L								
	Accelerate	-	-	-	-								
	Decelerate	L	L	-	M								
	Change Lane	L	L	-	-								
(4) 	Maintain Speed	-	-	-	-								
	Accelerate	-	-	-	L								
	Decelerate	-	-	-	-								
	Change Lane	-	-	-	-								
(5) 	Maintain Speed	-	-	-	-								
	Accelerate	-	-	-	-								
	Decelerate	-	-	-	-								
	Change Lane	-	-	-	L								
(6) 	Maintain Speed	-	-	-	-								
	Accelerate	-	-	-	-								
	Decelerate	-	-	-	-								
	Change Lane	-	-	-	-								
(7) Fixed Objects	Curb with Curvature	L	L	-	-	M	M	L	M	M	H	L	L
	Curb on straight Lane	-	-	-	-	-	-	-	L	L	L	-	L
	Parked Vehicle Heading Out	-	-	-	-	L	M	-	L	L	M	L	L

Vehicle S: Subject Vehicle
Vehicle A: Threat to Safety

Risk Level
- : No Risk
L : Low
M : Medium
H : High

Table 2 summarizes the risk level of threats to safety when driving under a synchronized flow. In this condition, speed adjustment is influenced by other vehicles since there are threats exist inside the reaction and critical domains. Objects inside the reaction domain would be considered as posing a higher risk than those inside the perception domain. Furthermore, threats in all three domains would attract drivers' attention. Although drivers look at the near side of the road, objects inside the perception domain will occasionally draw their attention, even though the threats in this area pose less risk than those in the reaction and critical domains.

Table 2 – *Risk level of threats to safety in synchronized flow*

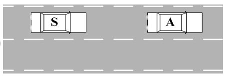
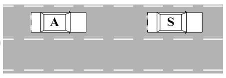
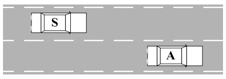
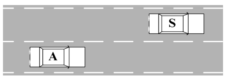
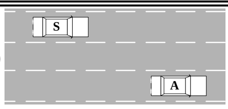
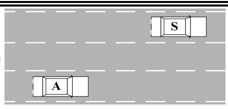
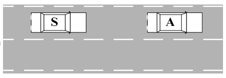
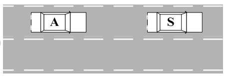
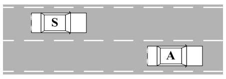
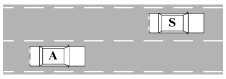
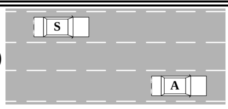
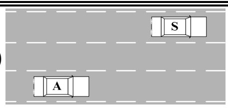
Maneuver Undertaken by Vehicle A \ Maneuver Undertaken by Subject Vehicle		Subject Vehicle Driving in Synchronized Flow											
		Perception Domain				Reaction Domain				Critical Domain			
Related Location of Threats	Maneuver	Maintain Speed	Accelerate	Decelerate	Change Lane	Maintain Speed	Accelerate	Decelerate	Change Lane	Maintain Speed	Accelerate	Decelerate	Change Lane
(1) 	Maintain Speed	-	L	-	-	M	M	-	L	H	H	M	M
	Accelerate	-	-	-	-	L	M	-	-	M	H	L	-
	Decelerate	L	L	-	-	M	H	M	L	H	H	M	L
	Change Lane	-	-	-	L	-	L	-	M	M	M	L	H
(2) 	Maintain Speed	-	-	-	-	L	-	L	-	M	M	M	L
	Accelerate	-	-	L	-	M	L	M	L	H	M	H	M
	Decelerate	-	-	-	-	-	-	-	-	M	L	L	-
	Change Lane	-	-	-	-	-	-	-	-	L	-	L	M
(3) 	Maintain Speed	-	L	-	L	L	M	-	M	M	M	L	H
	Accelerate	-	-	-	-	-	L	-	L	L	M	-	M
	Decelerate	-	L	-	L	L	H	L	H	H	H	M	H
	Change Lane	L	L	-	-	M	H	L	L	H	H	M	M
(4) 	Maintain Speed	-	-	-	-	-	-	-	M	M	L	L	M
	Accelerate	-	-	-	-	L	L	L	H	M	M	M	H
	Decelerate	-	-	-	-	-	-	-	L	L	-	M	M
	Change Lane	-	-	-	-	L	L	M	M	M	L	M	L
(5) 	Maintain Speed	-	-	-	-	-	-	-	L	-	-	-	-
	Accelerate	-	-	-	-	-	-	-	-	-	-	-	-
	Decelerate	-	-	-	-	-	-	-	L	-	-	-	L
	Change Lane	-	-	-	L	L	M	-	M	-	-	-	L
(6) 	Maintain Speed	-	-	-	-	-	-	-	-	-	-	-	-
	Accelerate	-	-	-	-	-	-	-	L	-	-	-	-
	Decelerate	-	-	-	-	-	-	-	-	-	-	-	-
	Change Lane	-	-	-	-	-	-	L	M	-	-	-	L
(7) Fixed Objects	Curb with Curvature	L	L	-	L	L	M	-	L	M	H	L	M
	Curb on straight Lane	-	-	-	L	-	-	-	L	L	L	-	M
	Parked Vehicle Heading Out	-	-	-	-	L	L	L	M	L	L	M	M

Table 3 summarizes the risk level of threats to safety when driving under a congested traffic flow condition. Under such a condition, the headway between vehicles is small, so drivers must accelerate and decelerate frequently. The area to which drivers can allocate attention is limited. Most of the time, drivers can focus only on the vehicles ahead that are located near the critical boundary to prevent accidents (as in the first scenario). Although vehicles appear in the perception and reaction domains, they do not produce safety-critical information that a driver must perceive. Moreover, considering that the gap between two vehicles is very small, drivers may not worry about vehicles in adjacent lanes, since there is apparently no available space for changing lanes. A driver would typically pay attention to traffic in adjacent lanes only when Vehicle S or a vehicle in an adjacent lane is signaling a lane change (as in the third and fourth scenarios).

Table 3 – *Risk level of threats to safety in congested flow*

Maneuver Undertaken by Vehicle A \ Maneuver Undertaken by Subject Vehicle		Subject Vehicle Driving in Congested Flow											
		Perception Domain				Reaction Domain				Critical Domain			
Related Location of Threats	**Maneuver**	Maintain Speed	Accelerate	Decelerate	Change Lane	Maintain Speed	Accelerate	Decelerate	Change Lane	Maintain Speed	Accelerate	Decelerate	Change Lane
(1) 	Maintain Speed	-	-	-	-	-	-	-	-	H	H	M	M
	Accelerate	-	-	-	-	-	-	-	-	M	M	L	L
	Decelerate	-	-	-	-	-	-	-	-	H	H	M	H
	Change Lane	-	-	-	-	-	-	-	-	M	M	L	H
(2) 	Maintain Speed	-	-	-	-	-	-	-	-	-	-	-	-
	Accelerate	-	-	-	-	-	-	-	-	-	-	-	-
	Decelerate	-	-	-	-	-	-	-	-	-	-	-	-
	Change Lane	-	-	-	-	-	-	-	-	-	-	-	-
(3) 	Maintain Speed	-	-	-	-	-	-	-	M	-	-	-	H
	Accelerate	-	-	-	-	-	-	-	L	-	-	-	M
	Decelerate	-	-	-	-	-	-	-	H	-	-	-	H
	Change Lane	-	-	-	-	-	-	-	L	H	H	M	L
(4) 	Maintain Speed	-	-	-	-	-	-	-	M	-	-	-	M
	Accelerate	-	-	-	-	-	-	-	H	-	-	-	H
	Decelerate	-	-	-	-	-	-	-	L	-	-	-	M
	Change Lane	-	-	-	-	-	-	-	-	-	-	-	-
(5) 	Maintain Speed	-	-	-	-	-	-	-	-	-	-	-	-
	Accelerate	-	-	-	-	-	-	-	-	-	-	-	-
	Decelerate	-	-	-	-	-	-	-	-	-	-	-	-
	Change Lane	-	-	-	-	-	-	-	-	-	-	-	-
(6) 	Maintain Speed	-	-	-	-	-	-	-	-	-	-	-	-
	Accelerate	-	-	-	-	-	-	-	-	-	-	-	-
	Decelerate	-	-	-	-	-	-	-	-	-	-	-	-
	Change Lane	-	-	-	-	-	-	-	-	-	-	-	-
(7) Fixed Objects	Curb with Curvature	-	-	-	-	-	-	-	-	L	L	L	L
	Curb on straight Lane	-	-	-	-	-	-	-	-	-	-	-	-
	Parked Vehicle Heading Out	-	-	-	-	-	-	-	-	-	-	L	L

The risk level of threats to safety is a subjective index since drivers make decisions based their subjective perception towards the driving environment. This index may be influenced by differences in the driver's individual characteristics. The heterogeneity of the driving population may result in different perceived risk levels with identical threats. The issue of heterogeneity, although not considered in this study, should be seriously addressed and analyzed in the future. Nevertheless, the risk level summarized in this section is an important index to help clarify the process of driving attention allocation and provides a framework for identifying the location and possible risk level of threats in different domains. This research only summarized the concept and the general condition of risk level that driver might perceive in certain traffic flow condition. Field data collection is necessary in future studies.

Attention Allocation in Vehicle Driver's Domains

The real driving environment can be seen as a dynamic system containing multiple time-dependent safety threats. Drivers should keep switching their attentive focus between different threats. However, owing to differences in behavioral intention, traffic conditions, and other heterogeneities in the external environment, the duration and sequence of focusing on a specific object while driving and the driver's subsequent behavior vary with the situation. It is important to identify whether drivers allocate enough attention to critical objects that may threaten safety. Misallocating attention may cause failure to perceive critical information and inability to react to possible dangers in time. To analyze the attention shifting process and behavior, this research proposes a driving attention allocation model for analyzing transitions in a driver's attentive focus.

The divided attention model suggests four attributes. First, the available mental resources are limited and vary with the driver's arousal level. Second, the allocation of mental resources and attention is based on the risk levels of threats. Objects with higher risk level demand more attention from the driver. Third, attentional resources are divisible. As long as the attention required is below the capacity limit, the attention can be divided and allocated to different foci, including threats to safety and other distractions. Fourth, a central attention allocation policy exists for controlling and selecting the attentive focus. Due to their training, experience, and intentions, different drivers may have different allocation strategies and allocate different levels of attention in collecting different information.

The framework of driving attention allocation is shown in Figure 8. Driving status can be represented by enduring disposition and momentary intention. The enduring disposition reflects the characteristics of all objects in the environment that would remain for a period of time. In this research, it is characterized by traffic flow conditions and other vehicles' relative locations, distances, and maneuvers. Momentary intention denotes the driver's intention to undertake a certain behavior. This research considered four possible behaviors: maintaining speed, acceleration, deceleration, and changing lanes. Events occur if the enduring disposition is interrupted, or if a driver actively changes his or her intention to undertake certain maneuvers. By determining the driving status in terms of the enduring disposition and momentary intention, threats to safety are identified and assigned to different domains based on the characteristics of the vehicle driver's domain.

The risk level in each domain, which is the summation of the risk level of each threat to safety inside the domain, is the input of the attention allocation policy. It is considered to be the combined index of enduring disposition and momentary intention. Threats to safety may vary with traffic flow conditions, the objects inside the domains, and driving maneuvers. R_{PD}, R_{RD}, and R_{CD} represent the risk level of threats to safety in the perception, reaction, and critical domains, respectively. As introduced in Table 1 to Table 3, the risk level varies with the characteristics of the vehicle driver's domain and the interaction between the subject vehicle and threats in each domain. More significant threats inside a specific domain will attract more attention to maintain safety.

The core of the driving attention allocation model is the allocation policy, which refers to the strategy of allocating mental resources. Drivers might attend to five major attentive focuses: the three vehicle driver's domains and two distraction domains. To collect complete information, drivers would tend to switch their attentive focus between different on-road, off-road, or in-vehicle areas. The contents of each of the vehicle driver's subdomains provide information for use in driving maneuvers and accident prevention. Some content may be treated as threats to safety that require more attention. On the other hand, distractions are information induced by off-road or in-vehicle stimuli. Two types of distraction are possible. The first is information about driving, including driving speed information on the dashboard, route information on navigation systems, and regulation information on off-road signs. Collecting such driving-related information would help enhance the understanding of traffic conditions and control of driving activities. The second type of distraction is non-driving-related information including cell phone conversations, music from the radio, or interesting off-road objects. Such non-driving distractions may degrade safety by shifting attention away from driving tasks. However, it also provides positive effects, such as entertainment or maintaining a minimum workload to prevent passive fatigue.

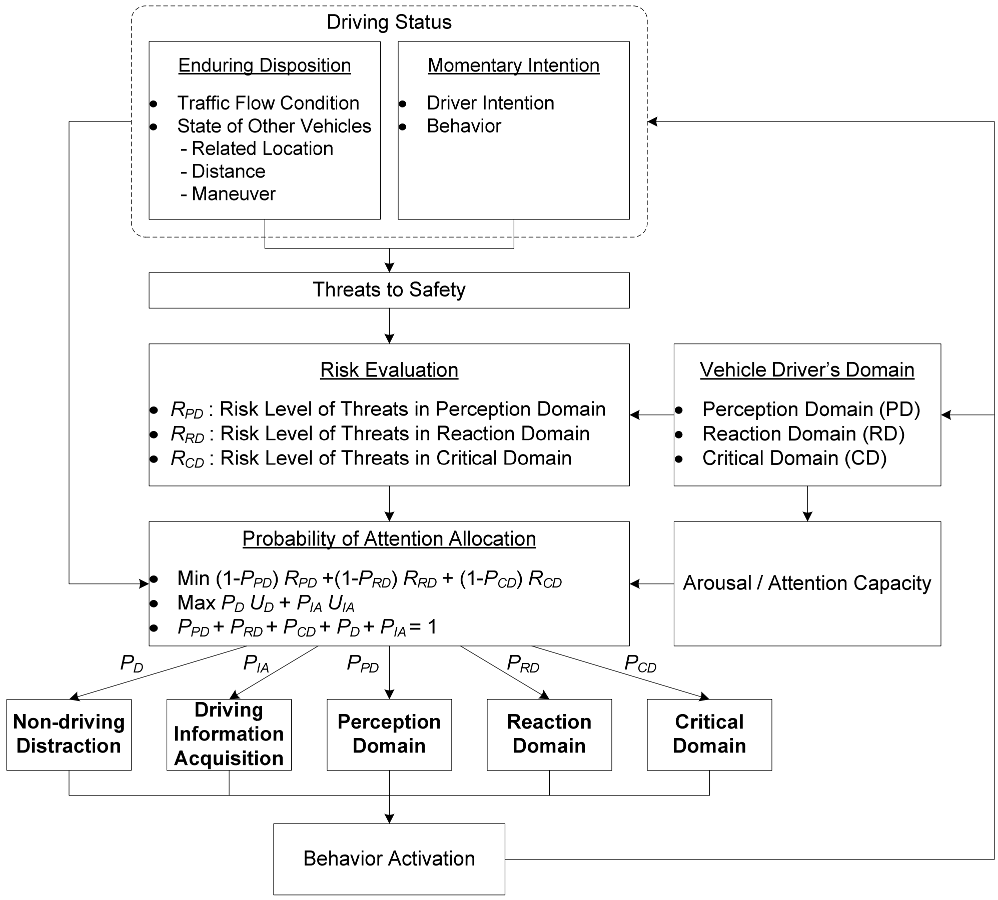


Figure 8 – *Framework of driving attention allocation model*

The allocation policy depends on the driver's intention, the risk level of threats to safety in different traffic flow conditions, and the driver's attention capacity. The demands on attention in each area differ with traffic conditions and driving environment. For example, while driving in free flow traffic, the risk level of threats to safety is comparatively low. Speed information on the dashboard must be collected by drivers to prevent speeding. In contrast, in congested flow, speed information is no longer necessary, since all vehicles are driving slowly in a traffic jam. This case indicates that the definition of complete information is unique to the situation. It is important to identify the required information that drivers should collect in different conditions.

The probability of allocating attention to the perception, reaction, and critical domains ($P_{PD,}$ P_{RD} and P_{CD}, respectively) can be obtained by minimizing the expected total risk of not paying attention to a specific domain. Additionally, a driver would also consider the utility derived from time spent on distractions. Despite allocating attention to the three domains on the road, distractions are also important domains that may consume attention capacity and mental resources. In this research, the probability of non-driving distractions (P_D) and the probability of driving information acquisition (P_{IA}) represent the proportion of time spent on distractions and on driving tasks, respectively. The existence of and increase in distraction probability would decrease the total probability of allocating attention to driving tasks, compromising driving safety. However, drivers would still try to maximize the utility from distractions (U_D and U_{IA}). To identify the effect of distractions such as in-vehicle information systems or cell phone usage while driving, it is important to clarify the effect of distractions in the model of driving attention allocation.

The driving attention allocation model proposed in this research is a domain-based analysis, not an approach based on individual threats. The probability obtained through the framework in Figure 8 represents the proportion of time a driver spends on each domain (including the two types of distraction) in a relatively short period of time regarding one specific event. The state of the vehicle driver's domain, which is represented in size and shape, and the contents of each sub-domain, will be revised with changes in the driving environment, event, and driver's intention. This research does not address attention allocation to each threat inside the three vehicle domains. Threat-based attention allocation can be seen as the second level of the attention allocation model. Strategies of choosing attentive focus for individual threats can still be obtained by minimizing the risk inside the domain selected in the previous stage. However, the sequence of attentive focus transitions and the interaction between threats should be addressed in a disaggregate attention allocation analysis.

CONCLUDING REMARKS

Although widespread concern about accident-prone scenarios exists, the nature of accidents is still implicit without further exploration of the mental process of driving. To clarify the role of drivers in the accident chain and to better understand the missing link between accident-prone scenarios and accident occurrence, the issue of attention should be addressed. Based on the divided attention model, this research proposed a driving attention allocation model for identifying the mechanisms of allocating mental resources among different driving activities. Moreover, considering the complexity of a real driving environment in which too many objects may provide information for drivers to collect, the concept of the vehicle driver's domain is proposed to classify the threats to safety into three domains. Applying the attention allocation model in accident chain analyses enables discussion of complete information collection. This research is the first step in elucidating the driver's mental processes. Aspects of driving attention allocation still require further discussion and study.

In this attention allocation model, the probability of attention allocation is obtained by minimizing the risk level of threats to safety. However, a driver's true attention allocation will not agree completely with the optimized results. In fact, different drivers with unique driving experience, behavioral intentions, and personality may have varying probabilities of attention allocation. For example, novice drivers may give more attention to objects on the road, while experienced drivers may have spare mental resources allocated to external information collection. The effect of heterogeneity in individual characteristics on attention allocation must be identified.

Moreover, this research focuses only on the allocation policy for identifying the amount of mental resources consumed by specific activities. This model treats the maximum attention capacity as an exogenous factor. Arousal is defined as the contributing factor that determines the available mental resources. It has been suggested that the effect of arousal on attention allocation is U-shaped (Kahnement, 1973). Over-arousal and under-arousal will not activate adequate attention capacity and will degrade driving safety. The issue of arousal and attention capacity under different physiological conditions must be addressed.

Another issue that needs more discussion is the connection between tasks and attention allocation policy. It is assumed that drivers must collect complete information to maintain safety. However, different conditions of traffic flow, driving environment, information availability, and the driver's behavioral intention may cause different levels of distraction in information collection. The importance of the interaction between threats and events is vital when undertaking attention allocation analysis on the basis of individual threats.

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